THE SOCIAL AND ECONOMIC VALUE OF EARTH OBSERVATION DATA

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STATEMENT

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Lewis Miller

ABSTRACT

Throughout the development of the remote sensing industry, social and economic value of Earth Observation data has been measured using contributions to scientific understanding and market prices. Neither approach is satisfactory because Earth Observation data adds value to a broad range of activities, within and outside markets. A repeatable strategy for effectively capturing value is proposed to support full and comprehensive assessment of so-far missing markets in Earth Observation. Complete value-capture serves two purposes; to permit fair competition with more commercial market alternatives and to allow informed management in the absence of traditional market forces. Disciplines such as environmental accounting and law provide guidance for complex valuation. Rigorous examination of value characteristics had not been undertaken in Earth Observation before this research. An innovative map of value components is constructed using coordinates of rivalry and excludability. Pre-existing valuation schemes are simplistic and do not capture value with sufficient precision or in enough depth to support informed management and decision-making. The broad range of value characteristics found within Earth Observation suggest that 'one size fits all' data policies are inappropriate. Case studies in Forestry and Humanitarian Aid are used to explore components of Earth Observation value and to develop a model for capturing value. Both case studies suggest that Earth Observation benefits often reside outside markets in the form of improved decision-making, more effective and efficient staff deployment and more focused management and mitigation activities. The new model of value presented in this thesis consistently captures components of value which have in the past been incompletely or poorly represented. This is both important and timely; non-market socio-cultural impacts, such as improved strategic decision-making and information-collection have recently been recognised as key outputs of Earth Observation through GMES and the Global Earth Observation System of Systems (GEOSS).

CONTENTS

FIGURES

TABLES

GLOSSARY

ACH	Analysis of Competing Hypotheses
ASTER	Advanced Spaceborne Thermal Emis. Reflec. Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CNES	Centre Nationale d'Etudes Spatiales
COFUR	Cost of Fulfilling User Requests
DMC	Disaster Monitoring Constellation
ECHR	European Convention on Human Rights
ERS-1	Earth Resources Satellite 1
ESA	European Space Agency
EU ETS	EU Greenhouse Gas Emissions Trading Scheme
FBC	Faster-Better-Cheaper
FEWS	Famine Early Warning Service
GAAP	Generally Accepted Accounting Principles
GDP	Gross Domestic Product
GEM	Global Environmental Markets
GEOSS	Global Earth Observing System of Systems
GIS	Geographic Information System
GMES	Global Monitoring of Environment and Security
ICSMD	International Charter for Space and Major Disasters
IDP	Internally-Displaced Persons
IPR	Intellectual Property Rights
IRIN	Integrated Regional Information Network
ISDR	International Strategy for Disaster Reduction
***k*NN**	*k*-Nearest Neighbour
MARS	Monitoring Agriculture with Remote Sensing
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectro-radiometer
MSG	Meteosat Second Generation

MSS	Landsat Multi Spectral Scanner
NGO	Non-Governmental Organisation
NIPA	National Income and Product Accounts
NOAA	National Oceanographic and Atmospheric Administration
NWP	Numerical Weather Prediction
PAHO	Pan-American Health Organisation
TESEO	Treaty Enforcement Services using Earth Observation
TEV	Total Economic Value
TM / ETM+	Landsat Thematic Mapper / Enhanced Thematic Mapper +
TREES	Tropical Ecosystems Environment Observation by Satellites
(A)SAR	(Advanced) Synthetic Aperture Radar
SPOT	Systéme Probatoire pour L'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
UNDP	UN Development Programme
UNFAO	UN Food and Agriculture Organisation
UNGFMC	UN Global Fire Monitoring Centre
UNHCR	UN High Commission for Refugees
UNITAR	UN Institute for Training and Research
UNOCHA	UN Office for the Coordination of Humanitarian Affairs
UNOPS	UN Office for Project Services
UNOOSA	UN Office for Outer Space Affairs
UNWFP	UN World Food Programme
USAID	US Agency for International Development
USDC	US Department of Commerce
USGS	US Geological Survey
VHR	Very High Resolution
WMO	World Meteorological Organisation
WTA / WTP	Willingness to Accept Compensation / Willingness to Pay

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Chapter 1 INTRODUCTION

1.1 Motivation and Aims

While Earth Observation has made a major contribution to the monitoring of planet Earth, it has not received as much media attention in the UK as other space activities such as planetary exploration, navigation or communications. *New Statesman* (2002) summarises that "when people thought of mankind's future in space, they thought of settlements on the Moon, expeditions to Mars, mining the asteroid belt and so on. The role of near-Earth satellites was hardly discussed". Increased use of satellite mapping in advertising and broadcasting (particularly Google Earth coverage) has altered public perception of Earth Observation (ABC News 2005, Randerson 2006, Cooper 2006).

Outside media coverage, satellites have enabled scientific progress, facilitated economic development and provided information for treaty enforcement and environmental monitoring (TESEO 2001, TREES 2005, MARS 2006). Satellite activities also support a UK space industry which has a turnover of £2.9 billion per year (Cookson 2002). Throughout the development of the remote sensing industry, the value of Earth Observation data has been measured in two ways. Economic value is represented using market price of data and social value is assessed using contributions to scientific understanding. Neither approach is satisfactory because Earth Observation data adds value to a broad range of environmental, humanitarian, legal and scientific activities which take place both within and outside markets. If components of value are ineffectively captured and stated, the value of Earth Observation data is incompletely represented, and satellite remote sensing activities risk being regarded as little more than "an expensive diversion" (Johnson 2002). The exclusion of benefit streams that reside outside the market from sectoral valuation of Earth Observation complicates advocacy, and prevents the effective representation of the sector to government and other funding bodies. Poor capture of largely societal non-market benefits places the future provision of such benefits in jeopardy. Conversely, if a repeatable strategy to capture value can be proposed that effectively accounts for humanitarian and environmental factors, then the so-called missing markets of Earth Observation data can finally be considered in a full and comprehensive manner.

One of the reasons it has been problematic to assign monetary values to Earth Observation data is that estimates of space industry size and growth vary widely (Hertzfeld 2002), reflecting inconsistent approaches by agencies and investigators and the lack of standardised assessments (Federal Geographic Data Committee 2002). Further complications arise because of significant government use of civil remote sensing, alongside a large classified and military sector. Statistics measuring the size and performance of government agencies are not always comparable with private-sector figures; operations and requirements are diverse and disparate. The European Space Agency notes that "difficulties in measuring commercial satellite markets have arisen in the past due to the secrecy surrounding commercial contracts, the exact contents of commercial deals, and the payment plans associated with programme milestones" (ESA 2004). Schleicher-Tappeser (2000) warns of the complexities of applying market metrics to geographic information, and states that "combining the supply characteristics of present and future needs of different user groups in different kinds of activities leads to a very large amount of required data."

1.2 Scope

The value of spaceborne Earth Observation is implicit rather than explicit. It is naturally assumed rather than being objectively stated. Leaving aside discussions of airborne sensing, which is bound by different legal and policy structure, a systematic examination of the value of spaceborne Earth Observation data is required. Using other sectors with non-market benefit streams and complex, intangible outcomes to identify categories of value, it is possible to design a methodology for completely and representatively capturing the value of data. Once the true value is known, data can be more effectively used in planning and as a policy tool. In addition, the performance of the Earth Observation sector can be more consistently evaluated alongside other space technologies. Potential users of Earth Observation could make better and more informed decisions if data value was reported more completely and consistently.

It is important to assess value logically in a way that allows inter-comparison because Earth Observation can serve many users and support diverse activities (Schleicher-Tappeser 2000). A flexible general model of value can assist a wide range of users who may not possess expert knowledge of data types and capabilities. The effective deployment and testing of a general model may reduce perceived barriers to entry for prospective data users.

1.3 Structure

The research reported in this thesis explores the concept of the value of Earth Observation data in four main ways. The first investigates categories of value employed by sectors outside Earth Observation and the space industry. Examining ways in which other disciplines attribute value to complex data, events and products allows recommendations to be made which inform later work. The second builds on categories of value and introduces data characteristics, which are evaluated by separating components of value and assessing their relative weights when applied to Earth Observation data. In the third section, a generalised and interdisciplinary model is developed using a detailed case study, set in the Forestry sector. In the fourth section the model is refined and tested within the Humanitarian Aid sector. Choice of case study was influenced by differences between foresters and humanitarian aid workers; foresters' objectives include efficient landscape management and maximised commercial productivity, but for Humanitarian Aid there are few commercial opportunities for geospatial market development, which has led to poor sectoral development. If the model final iteration is applicable in these very different environments it can be recommended for general use. Model performance is assessed and discussed with reference to case study results and future implementations.

1.4 Categories of Value

Strategies for attributing and measuring the value of intangible information have been developed within other disciplines (Nordhaus and Kokkelenberg 1999, Macauley 2006). These categories of value can inform the management of Earth Observation data. Challenges of capturing social and economic value have also been addressed in other fields, and reported through social science and economic literature. The following approaches to categorising value are investigated:

- Environmental
- Economic
- Legal
- Security
- Forestry
- Humanitarian

1.5 Data Attributes and Value

Environmental, economic and legal fields provide an overview of existing categories of value and illustrate different levels of policy and methodological development. Following this, an investigation of Public Good value-components introduces terminology and clarifies the scope of later case studies. Value-types for digital data are complex, and correctly categorising information enables an informed and appropriate choice of management strategy. Case studies in forestry and humanitarian aid contribute to the formulation of a new generalised model which provides an accessible framework for assessing the total value of Earth Observation data.

Earth Observation competes at national and European level with other space activities for budgets and strategic consideration. Missing markets and uncaptured benefit streams lead to under-representation of data value, and a corresponding weakening of advocating arguments. In a rapidly developing sector there has been no rigorous investigation of data characteristics although they influence data pricing and distribution strategy. Sustainable data commoditisation and marketing relies on thorough product knowledge, yet such knowledge is not common among consumers or suppliers in the Earth Observation marketplace.

1.6 Model Development

Drawing on categories and components of value from other disciplines, two Earth Observation case studies are used to design and test a new general model of value. The value model is developed within the forestry sector, where Earth Observation data supports commercial timber extraction and sustainable management of a national environmental and leisure resource. Adoption of Earth Observation approaches has been inconsistent in the forestry sector, in line with nationally variable landscape cover and national economic importance of trees. The use of satellite data in most cases does not instigate a step-change in capability, and this is not sought by users. Subtle augmentations of current capabilities within tightly controlled budgets are the most common requirement. It is noted that Earth Observation data may prove pivotal in the delivery of international environmental reporting obligations (European Commission CORINE 2006).

Following this, the humanitarian aid sector is used to test and refine the model. Humanitarian applications are unusual because the sector is dominated by non-governmental organisations and charities, and many activities take place outside markets. Humanitarian activities do not generate data sales and do not contribute to scientific knowledge because technical requirements are typically modest and data suppliers and resellers have avoided the sector. Traditional valuation strategies would suggest that humanitarian applications cannot therefore contribute to value – an assertion that is clearly flawed. The general model of value aims to capture components of the value of Earth Observation which are omitted from traditional price-based or knowledge-driven approaches. It also allows effective advocation of Earth Observation data use, especially in competition with other approaches which may posses more accessible benefit streams, such as the communication and navigation sectors.

Chapter 2 APPROACH TO THE RESEARCH

2.1. *Demand for Research*

Dig the well before you are thirsty
(Chinese Proverb)

Earth Observation data contributes to the effectiveness of activities in scientific, legal, environmental, humanitarian, security and economic sectors which may not be represented in existing methods of capturing value. Improved capability, efficiency and capacity in these areas reflects positively on Earth Observation as a source of information for improved decision-making, but cannot currently add to value in an explicit way. Components of Earth Observation value are poorly understood, and progress in fields such as environmental accounting and economic or legal considerations of intangible assets have not been applied to satellite data valuation. In a report to the European Commission (Framework IV Report, Earth Observation Data Policy and Europe 2002) it was noted that "the question of price versus value is still unresolved consistently in Earth Observation" and that "detailed identification of value is usually only assessed in direct relation to a customer's information needs and willingness to pay". This thesis reports the results of research which aims to address these gaps in knowledge and proposes a more complete conceptual model for approaching valuation of Earth Observation data.

The market for Earth Observation data has not developed as rapidly as consumer markets in other space activities such as communications (Figure 2.1, Euroconsult 2002). It is important to understand development inhibitors in order to identify policy shortcomings and design appropriate mitigation strategies. The composition of Earth Observation value has seldom been examined. Poor market performance can be partly attributed to inappropriate development activities and unrepresentative valuation. Estimates of the social and economic value of Earth Observation are variable and inconsistent

(Hertzfeld 2002, ESA 2002, Ainsworth et al. 2001), but have primarily relied on two measures. Economic valuations have been based on data cost and related revenue-generation. Social value is commonly based on contribution to scientific understanding, largely isolated from marketed activities. Both approaches are flawed and neglect key contributions of Earth Observation data. Existing strategies of value-capture are often incomplete because non-market components are excluded. Use of unrepresentative financial indicators of market size or development leads to under-valuation. When flawed valuation approaches become accepted practice (as in the case of UK Generally Accepted Accounting Principles, collectively known as GAAP), decision-making is built on incomplete information. Incorrect policy weighting prevents decision-makers from seeing the potential of information sources, and leads to insufficient investment and poor sector profitability.

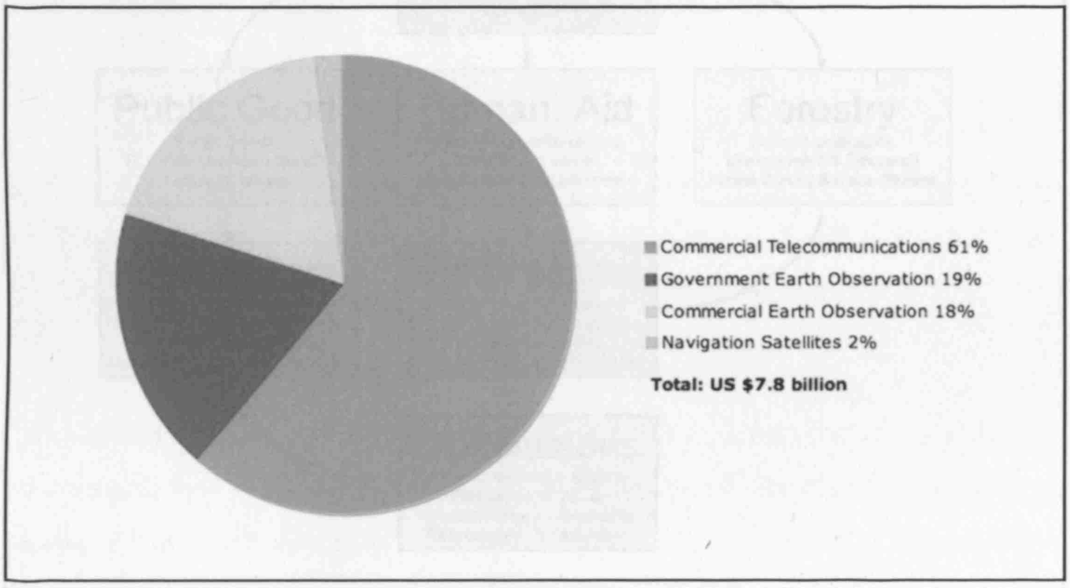

Figure 2.1 Comparison of space segment value for commercial and governmental satellite operations (adapted from ESA 2002)

This thesis aims to characterise social and economic components of Earth Observation value to permit their representation in a more complete, more repeatable and robust new valuation approach. Detailed case studies are used to design a model of value, which is refined through user feedback.

2.2. *Research Design*

2.2.1. **Route Maps and Plans**

Figure 2.2 illustrates the research design and shows relationships and links between the research components. Work is divided into preparatory and reviewing phases, development of a new model of value, and finally discussions and conclusions.

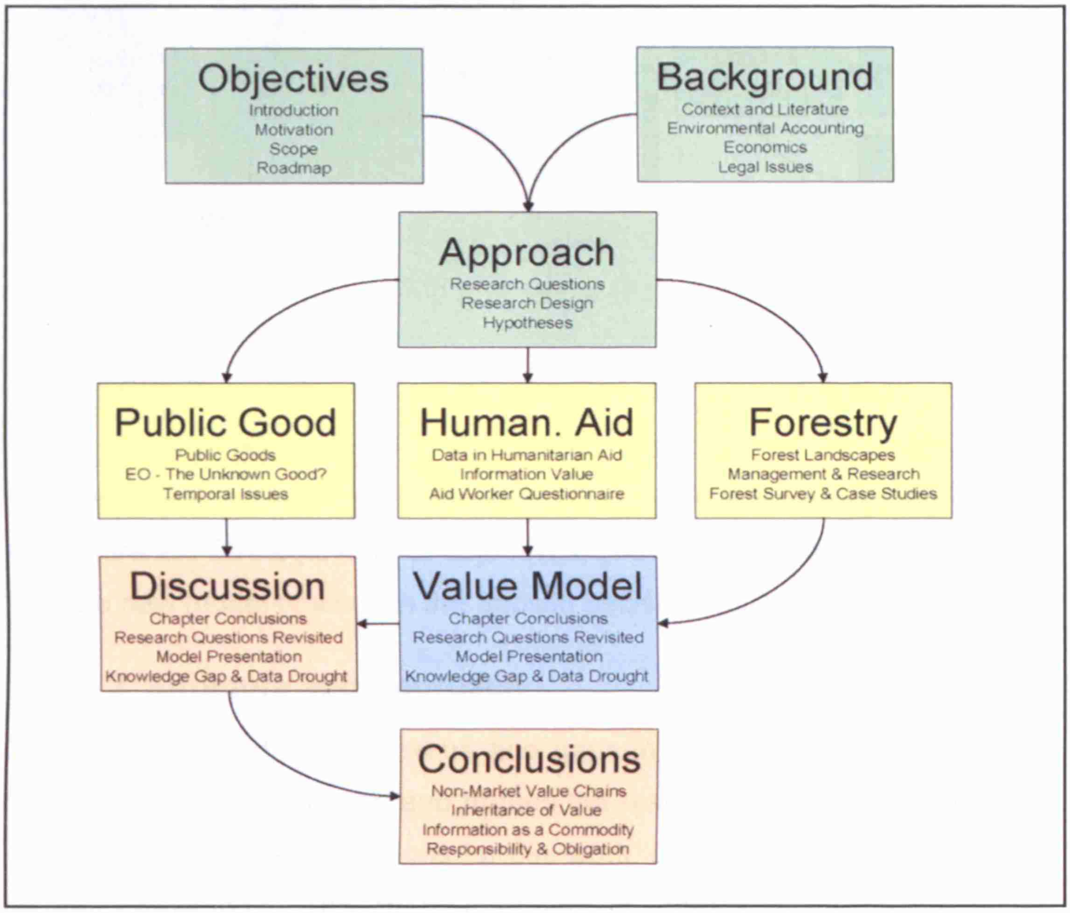

Figure 2.2 Thesis chapter structure and work flow.

A strategic map of objectives is shown in Figure 2.3, showing the position and function of a new model of value within the decision-making process. Without measuring tools to represent adequately the value of Earth Observation, any advocating position is weakened when compared with other options. In addition, no survey of current value-systems has yet been undertaken.

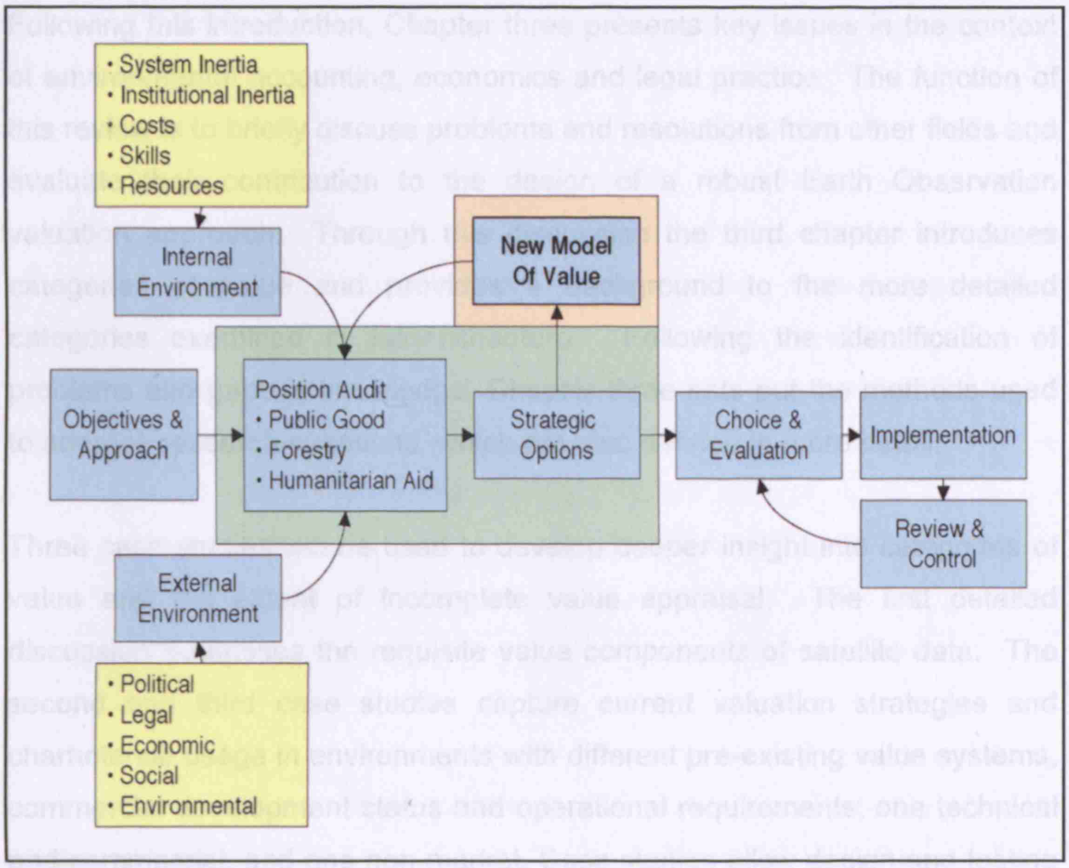

Figure 2.3 Strategic map of objectives, showing the position and function of a new model of value in the applied decision-making process.

2.2.2. Structure and Approach

Chapter one introduces problems and gaps in knowledge which justify the commencement of research and frames the research questions in a general sense. What are the motivations for this work, and where is the requirement for its completion? The chapter introduces themes of incomplete value-capture and notes that issues of complex valuation, where market prices do not fully represent true value, have been approached in other sectors in the past.

Building on identification of problems and gaps in knowledge, Chapter two sets out the research strategy and clarifies the thesis structure by summarising chapter objectives and approaches. Research questions are also presented.

Following this introduction, Chapter three presents key issues in the context of environmental accounting, economics and legal practice. The function of this review is to briefly discuss problems and resolutions from other fields and evaluate their contribution to the design of a robust Earth Observation valuation approach. Through this discussion the third chapter introduces categories of value and provides a background to the more detailed categories examined in later chapters. Following the identification of problems and gaps in knowledge, Chapter three sets out the methods used to address research questions, which are also defined in more detail.

Three case studies will be used to develop deeper insight into categories of value and the extent of incomplete value appraisal. The first detailed discussion addresses the requisite value components of satellite data. The second and third case studies capture current valuation strategies and characterise usage in environments with different pre-existing value systems, commercial development status and operational requirements; one technical and commercial, and one non-market. Case studies allow design and testing of a new conceptual model, which provides a novel approach for evaluating the true value of Earth Observation data sets. The choice of case studies ensures that a broad user-base is effectively served by the value model, which aims to include interactions and non-market elements which are excluded from traditional value assessments. Before the model can be developed, it is necessary to set out terminology and provide a framework for discussing the value-landscape of Earth Observation.

Chapter four introduces complex valuation and aims to discuss and map Public Good elements of Earth Observation value. Social and economic components of value have been considered by policy-makers, but the definitions used are incomplete and unrepresentative (Framework IV Report, Earth Observation Data Policy and Europe 2002, Georgiadou and Groot 2002, Federal Geographic Data Committee 2002). Many sub-categories can be identified within accepted definitions of social and economic value, and non-market value is often accepted only implicitly in legislation to ensure that human injury is prevented and welfare is maximised. The precise balance of value-components affects data set management, so understanding their scope and depth is important.

Chapter five uses Forestry as the first case study. The chapter plan is shown in Figure 2.4; it shows data preparation and detailed discussion with foresters at several levels of seniority in the UK and abroad. Questionnaires and interviews were used to characterise the ways Earth Observation data is currently used, and issues affecting uptake were discussed. Following discussions, further image processing was undertaken to evaluate the challenges and basic costs of acquiring information-products for forest management. Results are presented and discussed in Chapter five.

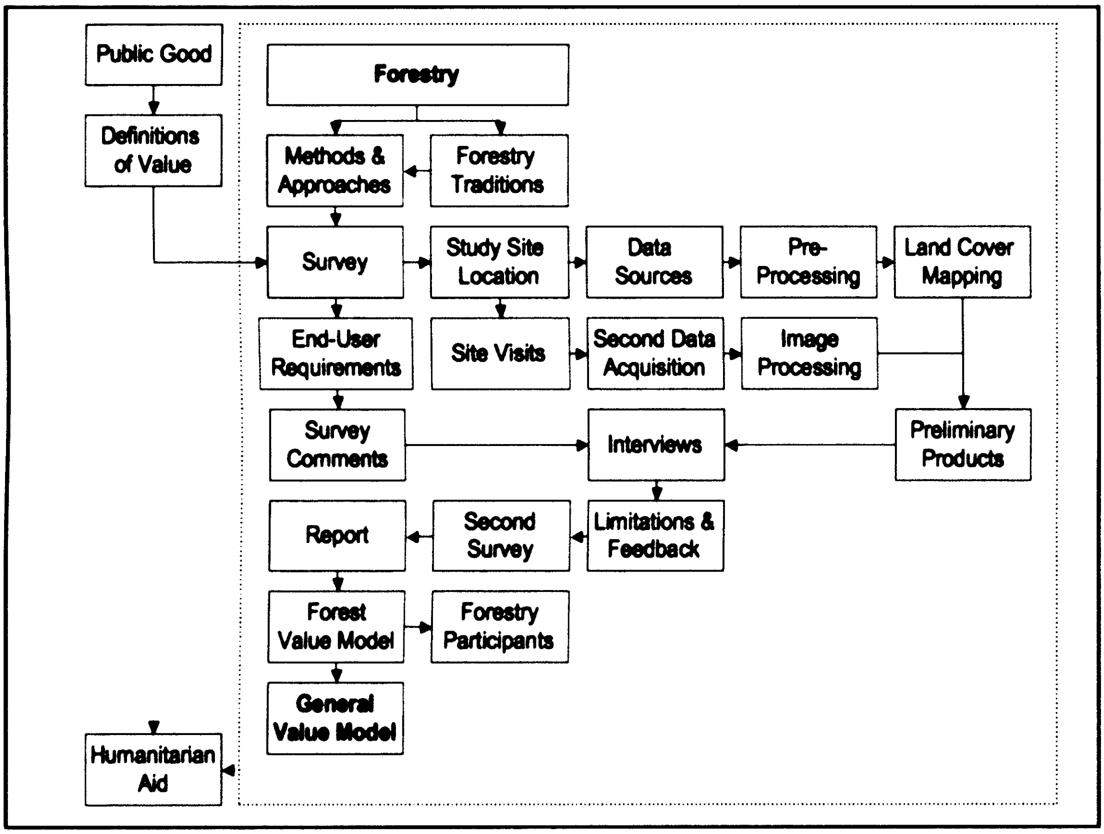

Figure 2.4 Strategic research plan for the analysis of the value of Earth Observation data in forestry, showing links with previous and subsequent chapters.

For many years it has been claimed that the needs of foresters are well served by Earth Observation approaches (Campbell 1996, Suarez 2002, Reese et al. 2003, Schuck et al. 2005). The core requirement is robust and repeatable data collection, to cover spatially extensive yet homogeneous areas of inaccessible forest with repeat observations which enable monitoring and management. Methods reliant on Earth Observation data aim to equal traditional forest surveying approaches in terms of accuracy, precision and cost-effectiveness. The importance of forestry in national landscape management is variable; for some nations, trees represent minority environments of interest as carbon sinks. For others, forest is an ecologically important habitat, historically neglected due to poor access, inhospitable terrain or other limiting factors (Frank and Müller 2003). In areas such as boreal and Scandinavian nations, forest is a dominant land cover and consequently provides significant employment and export revenue in terms of timber and other non-wood forest products.

Changing environmental legislation and increasing adoption of carbon accounting for environmental treaty compliance (Gilbert 2003) suggest that forest resource management will become much more information-intensive in future years, which brings responsibilities and commitments for managing even so-called wilderness forest areas (Häusler 2003, Jones, Bateman and Wright 2003, Slee 2004). For the purposes of this research, forestry is interesting for the following reasons:

- Earth Observation is a key information source for management and monitoring
- Market development is inconsistent and internationally variable
- Development of Earth Observation solutions is advanced in some nations
- Forestry is a partially commercial enterprise, driven by efficiency savings
- Non-profit forest managers will be forced by changing environmental legislation and carbon auditing to supply comparable data to commercial foresters

- Earth Observation is the only viable option for large-scale monitoring activities.

Responses from surveys, interviews and site visits supported the design of a model of value, as summarised in Figure 2.5. The generalised model (presented Figure 2.6) suggests a new way of approaching value in the evaluation of spatial data sources. Reflecting the development environment, four activities are identified; Mapping, Modelling, Management and Planning. Within each, data sources can be scored and prioritised according to how well they provide answers to operational questions. Chapter five discusses the development of the model, which is related in structure to Porter's five forces approach, which contests that "in any industry, whether it is domestic or international or produces a product or a service, the rules of competition are embodied in five competitive forces" (Porter 1985, Figure 2.7).

In Chapter five, a conceptual value model is parameterised using experiences of foresters (Figures 2.5 and 2.6). The model is refined and developed in Chapter six, which addresses data value and usage in the humanitarian aid sector. Split into three sections, the chapter examines the ways Earth Observation exploitation for the alleviation of human suffering reveals embedded non-market and Public Good value.

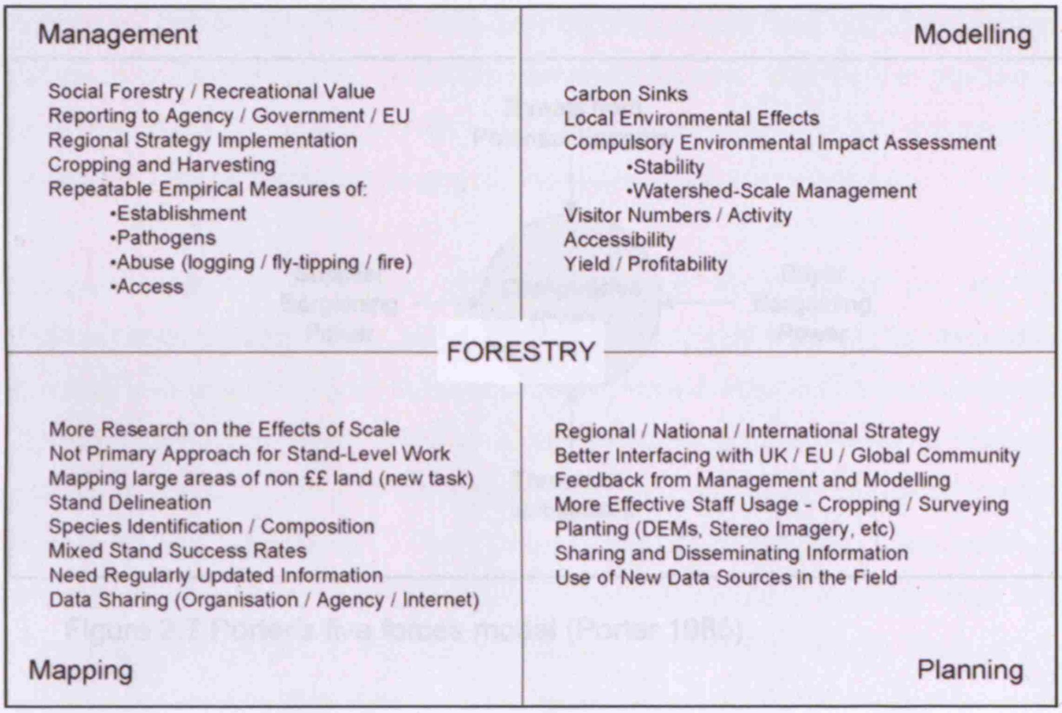

Figure 2.5 Original forestry-specific responses, which were generalised in the design of a new approach to valuation.

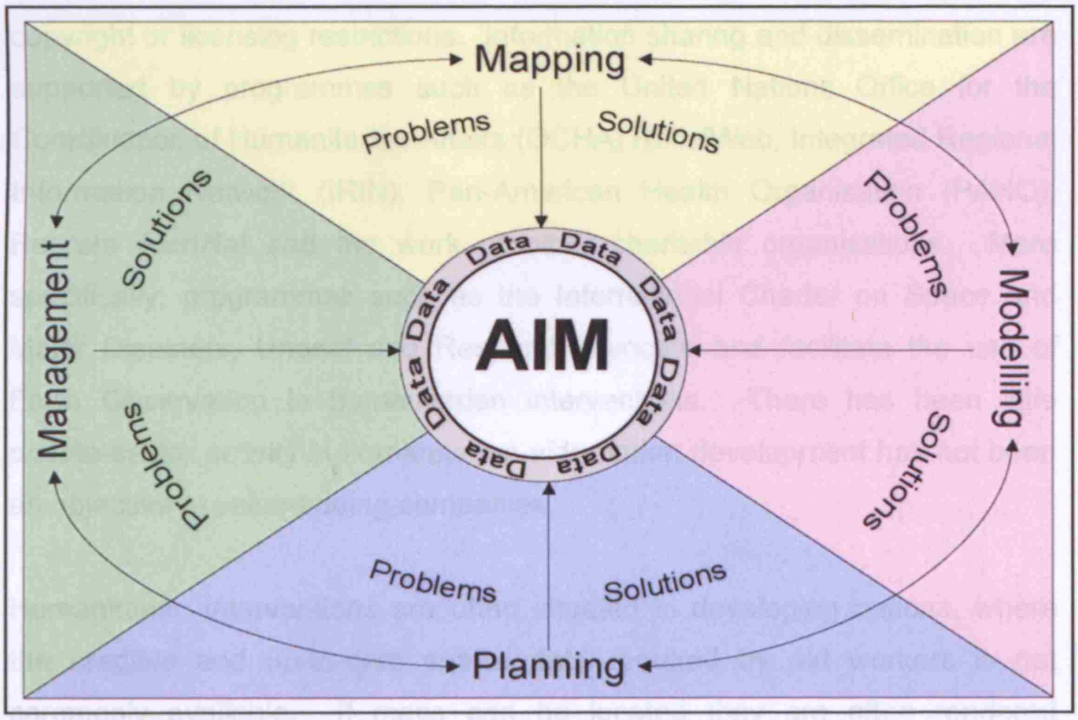

Figure 2.6 Generalised model of value defined using the forestry sector. The origin and design of the model is discussed in Chapter five.

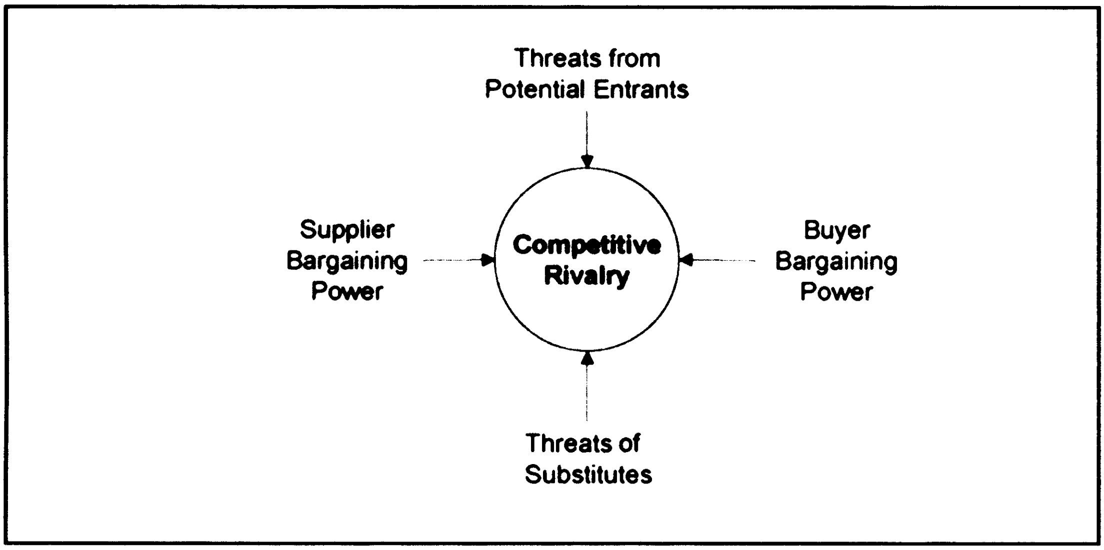

Figure 2.7 Porter's five forces model (Porter 1985)

Part one investigates the characteristics and requirements of humanitarian aid activities. Humanitarian aid work is an atypical discipline because there is very little commercial potential in humanitarian activities. Few markets exist so actors commonly share resources and are reluctant to be bound by copyright or licensing restrictions. Information sharing and dissemination are supported by programmes such as the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) ReliefWeb, Integrated Regional Information Network (IRIN), Pan-American Health Organisation (PAHO), Reuters AlertNet and the work of other charitable organisations. More specifically, programmes such as the International Charter on Space and Major Disasters, Unosat and Respond advocate and facilitate the use of Earth Observation in humanitarian interventions. There has been little private-sector activity in humanitarian aid; market development has not been an objective of value-adding companies.

Humanitarian interventions are often situated in developing nations, where the credible and up-to-date spatial data required by aid workers is not commonly available. If maps can be located they are often rendered obsolete by hazard events such as flood, fire, volcanic activity or earthquake. Technical requirements of humanitarian aid data users are modest; data coverage, currency and timeliness are more important than advanced image processing (Irving 2005, personal communication). Satellite images are primarily used in the creation of image-map products for emergency response, where rapid processing and dissemination are required.

Several attributes of Earth Observation data recommend its use in humanitarian emergencies. In the case of conflict or civil unrest, for example, the ability to synoptically monitor areas which are hazardous or inaccessible on the ground has been used to exert pressure on governments through public diplomacy, calling for more transparency and the admission of foreign human rights observers. The United States Agency for International Development (USAID) intervened to highlight ethnic cleansing and the destruction of villages in the Darfur region of Sudan as early as April 2004, six months before the first African Union human rights observers were admitted (BBC 2004, USAID 2006). While satellite images on the Internet helped to motivate international action, it was reported that "journalists and aid workers have minimal access to the conflict zone to check claims and counter claims by government and rebel commanders as well as displaced villagers" (*The Guardian*, 2006).

Humanitarian aid activities provide an informative case study for the following reasons.

- Earth Observation data can enable activities that were previously impossible
- The absence of cost-based markets and paying consumers reflects the 'social good' status of humanitarian activities
- Private-sector market penetration and development is minimal
- Earth Observation data is gaining support as a credible source of information
- Public diplomacy and publication of satellite surveillance images (by governments and NGOs) has altered public perceptions of Earth Observation
- Lack of information is regarded as a major inhibitor in aid activities

Part two of Chapter five discusses major programmes responsible for Public Good, Merit Good or Club Good provision of data in order to provide a contextual status review. The remit, extent and prerequisites of each programme are discussed, before part three appraises user experiences of data usage and applied value. Just as data was collected through questionnaires, site visits and interviews with foresters, information was gathered from humanitarian aid professionals from a range of backgrounds, in order to refine and develop a model of value, Figure 2.8. New elements of strategy and support were added, and a differentiation between hard and soft approaches was introduced to allow greater model applicability.

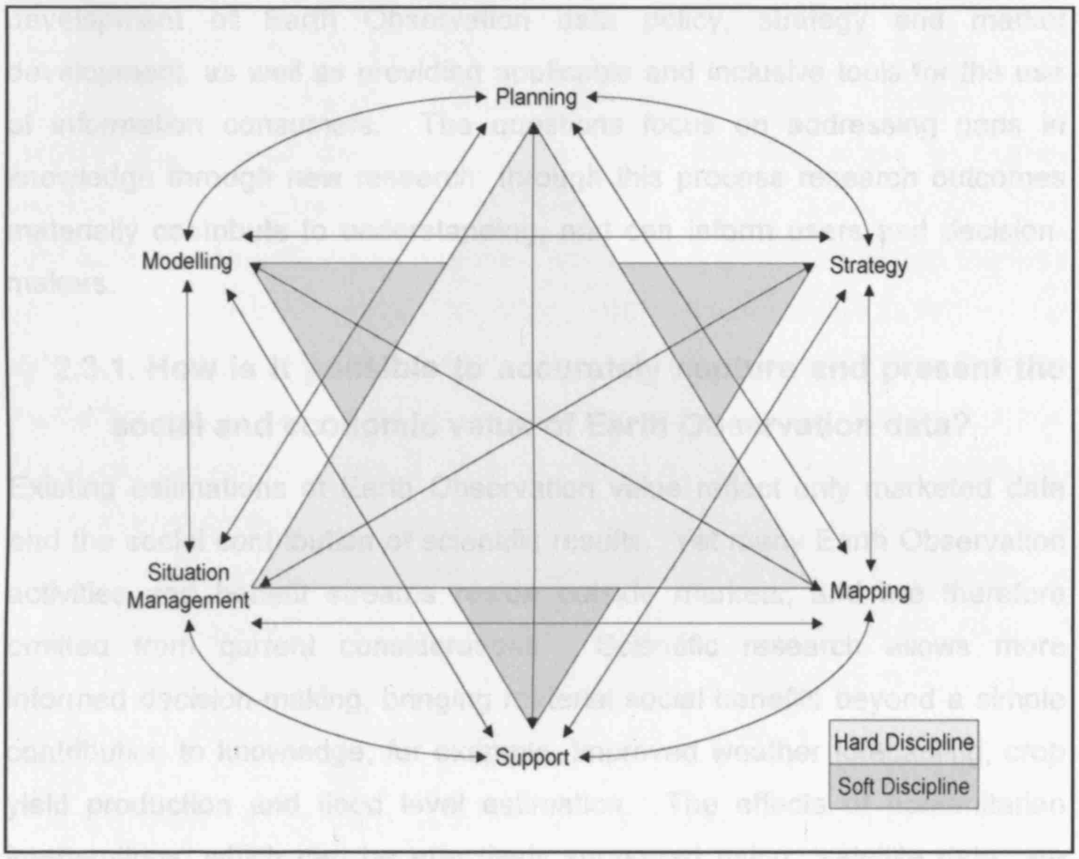

Figure 2.8 Conceptual model of value after introduction of non-market refinements using data from the humanitarian aid sector.

The final two chapters of this thesis assess the performance and applicability of the proposed value model in each of its iterations. The conceptual model is applied in forestry and humanitarian aid settings. The extent and success of representation of industry-specific issues is assessed. The validity of the case study structure and choice is considered, and cross-discipline conclusions regarding wider evaluation of Earth Observation data value are discussed. Finally, research questions are revisited, and the contribution to knowledge provided by the new generalised conceptual model of value is examined.

2.3. Research Questions

The following questions define the research objectives of this thesis. As well as contributing to the discussion on the value of Earth Observation data, the combined outcomes of these queries can inform and influence the development of Earth Observation data policy, strategy and market development, as well as providing applicable and inclusive tools for the use of information consumers. The questions focus on addressing gaps in knowledge through new research; through this process research outcomes materially contribute to understanding, and can inform users and decision-makers.

2.3.1. **How is it possible to accurately capture and present the social and economic value of Earth Observation data?**

Existing estimations of Earth Observation value reflect only marketed data and the social contribution of scientific results. Yet many Earth Observation activities and benefit streams reside outside markets, and are therefore omitted from current considerations. Scientific research allows more informed decision-making, bringing material social benefits beyond a simple contribution to knowledge; for example, improved weather forecasting, crop yield production and flood level estimation. The effects of humanitarian interventions, which can be effectively supported using satellite data, are excluded from these estimations yet such activities are clearly in the global public interest. It is proposed that a new type of value-assessment model can include non-market outcomes and less profitable activities that bring social and environmental benefits in the form of more sustainable development or land use, or more informed and efficient decision-making concerning natural goods and services.

2.3.2. To what degree is Earth Observation socially profitable, are "missing" markets important, and how can they be incorporated into valuation approaches?

If activities related to Earth Observation contribute to the reduction of human suffering, they are in the public interest and can be considered as formal Public Goods. Such activities are socially profitable, and may be worthy of public funding if no sustainable market can be developed (Georgiadou 2002). It is possible to investigate Public Good components of Earth Observation in three ways. Firstly, the data can be examined. Characteristics of rivalry and excludability can be mapped in a coordinate space, which gives an overall impression of the 'publicness' of the Good. Secondly the performance of existing markets can be assessed. When commodities with Public Good components are marketed, Tietenberg (2003) and Pearce (1996) warn of under-provision and excessive free-riding as the first signs of market inefficiency and failure. Special policies (such as taxes, quotas and centralised commodity provision) are required to maintain inefficient markets and prevent collapse. Finally, existing data policies can be examined for evidence of implicit Public Good provision. If policies already allow for non-market provision of goods for 'worthy causes' such as climate change research, humanitarian work or environmental monitoring, then decision-makers have accepted that social 'profits' justify the provision of data. After the Public Good status of Earth Observation data is clarified, appropriate management policies will aim to reduce unfair price-based exclusion of actors lacking an ability to pay. Inclusion of such actor's work in data value-audits is an important step towards representing true value.

2.3.3. Can a simple approach provide a logical, robust, consistent and interdisciplinary measure of total Earth Observation value?

Potential users evaluate the usefulness of Earth Observation on a haphazard and per-case basis (Twigg 2006, Woodhouse 2004, personal communication). It is proposed that a general model could be developed to function in a wide variety of end-user applications. The ability to model information linkages, working relationships and data life-cycles assists strategic planners. Insights into areas of increased capability or capacity help planners and strategists evaluate the potential operational impact of new information and working practices. Shortcomings can also be identified using modelling. Impact of some uptake inhibitors can be reduced by allowing planners without technical knowledge to model the impact of new approaches. By shifting the responsibility and capacity for feasibility studies from supplier to consumer, market development priorities shift from profit-maximisation to needs-based approaches which can be managed by users. To be effective, the model must be flexible enough to remain applicable in a wide variety of contexts, and incisive enough to provide useful guidance and act as an ongoing management tool.

Chapter 3 CONTEXT AND BACKGROUND

3.1. *Satellite Information*

Earth Observation images and other tangible data products are saleable commodities, but the revenue they generate does not reflect their total value. Key components are intangible and reside outside markets. Beyond data sales, there is economic value in reduced uncertainty and improved decision-making, so value-adding activities can be profitable for third parties (Williamson et al. 2001, Quaife 2005, personal communication). Multi-dimensional 'feature' information embedded within data can be interrogated to yield environmental information such as soil moisture, cloud-top temperature, surface topography or land cover (Campbell 1996, Lillesand and Kiefer 1994).

Satellites provide a unique platform for acquisition of data that would otherwise be unavailable or prohibitively expensive, from environments that may be hazardous, physically or politically unstable (Federal Geographic Data Committee 2002). Data are widely used by national agencies, governments and international entities to support decision-making and supply critical information. Some authors now consider that "confidence in remotely sensed geophysical signals has progressed to the point that the imagery can potentially be used alone to make accurate assessments of surface properties" (Armstrong 2000).

For purposes of governance, satellite-derived geospatial information has been extensively used in the following areas (Campbell 1996, George 2000, Federal Geographic Data Committee 2002, Williamson et al. 2002, Hertzfeld 2002, Priestnall and Aplin 2006).

- Transport and Development
- Agriculture
- Emergency Management
- Environmental Monitoring

- Defence and Security
- Natural Resource Management
- Energy
- Scientific Research

The proliferation of commercial remote sensing platforms means that both state and non-state actors are increasingly able to purchase high-quality images of the Earth's surface. In the past, a few elite agencies could access such data: in the future "every government and business, nongovernmental organisations, and terrorist and criminal groups" with sufficient purchasing power will have the capability (Tuchman-Mathews 2000). Wide availability and sharing of data is part of a global information revolution which demands, and has led to, greater transparency (Purdy and Macrory 2003, HMSO 2003). Management strategies and definitions surrounding this new market are incomplete, inconsistent and misleading. There is a clear requirement for new policy formulation and decision-making guidelines, to reflect new sensor capability and data processing capacity. "Mishandling the technologies and the policies that make such transparency possible would impose heavy costs in missed opportunities and potential threats. But if handled right [*sic*], the new transparency could offer enormous benefits for nations and peoples around the world" (Tuchman-Mathews 2000).

Missing markets and incomplete value-capture bring about skewed impressions of appropriate data cost. Harris (2003) concludes that "too often the call is heard that Earth Observation data is too expensive, a call that is hard to justify given the marginal cost price of much US and European data". Revenue streams generated from the collection, collation, processing and sale of Earth Observation data omit contributions these products make in the non-market arena. In many cases satellite data support improved decision-making or reduce redundancy. In others, data assist efficiency savings or increase capability and capacity. Benefits and services of this type are not captured by traditional pricing structures and reporting.

In this chapter the use and value of Earth Observation data are discussed with reference to wider issues of how to capture value. The chapter explores value-types and value-assignment approaches in environmental accounting and economics, and assesses the legal status of spatial information.

3.2. Literature Review

3.2.1. Environmental Economics

3.2.1.1. The Environment as a Good

In the case for intangible-good valuation, the environment provides an illustrative case study. Many ecosystem goods and services are inadequately valued, which leads to poor management and over exploitation because no quota or penalty system exists. Although it may seem somehow immoral to place a dollar value on a rainforest tree or a charming view, Herendeen (1998) states that "the argument that we lose our souls by economically pricing the environment is silly and ultimately counter-productive". Integrating environmental variables with markets provides important avenues for regulation. For as long as legislation demands threshold *values*, the preciousness of limited natural resources can be reflected by the installation of instruments to control their consumption and to make accountable those who consume them.

3.2.1.2. Nature and Dollar-Values

Arguments supporting moral opposition to environment pricing are weakened by everyday judgements that implicitly ascribe value to human life. Minimum engineering standards are set for bridge and tunnel construction "because spending more money on construction [over and above the minimum project cost] would save lives" (Costanza et al. 1997, Millard 1998). The same implicit valuation underpins healthcare spending, clean air and drinking water legislation.

The urgency of environmental accounting is highlighted by Costanza et al. (1998) who claim that "ecosystem [goods and] services are 'big potatoes' and we had better get busy and pay more attention to them". Increasing environmental pressure and changing legislation followed ratification of the Kyoto Protocol. Alongside reports indicating that "the benefits of strong and early action [to counteract anthropogenic climate change] far outweigh the economic costs of not acting" (Stern 2006) legal instruments provide incentives to protect natural assets, yet "evaluating the [assets] has proved difficult because they are mostly not captured by conventional market-based economic activity and analysis" (Balmford et al. 2002).

The natural environment is a source of many goods and services which are exploited for the generation of revenue. Limburg et al. (2002) recommend the use of 'ecosystem goods and services' terminology to "make it apparent that the structure and function of ecosystems provides value to humans". The value of natural resources, or environmental assets, is excluded from most forms of regional, national and global accounting, which count only marketed goods and services (Nordhaus and Kokkelenberg 1999). Many natural services are inherently non-market and are therefore omitted from such procedures. In the example of woodland, timber and non-wood products are marketable commodities. Other services and benefits from woodland take place outside the market so there is no financial reconciliation for loss of recreation, habitat and carbon sequestration when trees are harvested. The market value of forest products reflects and reimburses only the investment of time and labour required for harvesting. Environmental assets used in the growth of the woodland are never compensated in this form of asymmetrical accounting.

> We may have more houses, but if that means we have fewer trees and forests, something is seriously wrong with an accounting system that only adds up the houses (Costanza et al. 1998)

3.2.1.3. **Accounting Procedure**

Sutton and Costanza (2002) posit that traditional accounting strategies are out-dated, unsustainable and illogical when applied to environmental issues, because behavioural elements which influence welfare are omitted and it is unclear what industry-standard indicators measure. They state "from the perspective of GDP, more crime, more sickness, more war, more pollution, more fires, storms and pestilence are all good things, since they can increase marketed activity in the economy". There is a clear disconnection between valuation strategies and human welfare, which indirectly contributes to environmental degradation: oil spills increase GDP through costly clean-up efforts. Sustainable resource indicators must "represent the benefits human populations derive, directly or indirectly, from ecosystem functions" (Costanza et al. 1997). Few operational measures are capable of including intangible goods and services from which mankind benefits "aesthetically and culturally, via the provision of ecological services such as climate regulation, soil formation and nutrient cycling, and from the direct harvest of wild species for food, fuel, fibres and pharmaceuticals" (Balmford et al. 2002).

The absence of environmental variables from most accounting procedures inspired demand for a more representative way of discussing value in Economics. The design of economic tools which effectively integrate the natural environment is known as environmental economics. The discipline relies on principles of "sustainable scale, social fairness and economic efficiency" (Sutton et al. 1998). In many cases environmental economics contributes to sustainable development, which requires "a pluralist approach that involves (but does not reduce to) questions of environmental valuation" (Norgaard 1989). Although the economics of the natural environment has been the focus of great interest in recent years, initial concerns about missing markets of natural capital emerged in the 1960s and 1970s (King, 1966, Hueting 1970, cited by De Groot et al. 2002). The academic work was largely ignored until increasing inclusion of natural phenomena and measurements in environmental legislation in the early 1990s led to an "almost exponential growth in publications on the benefit of natural ecosystems to human society" and a consequent reconsideration of original principles (De Groot et al. 2002).

3.2.1.4. **The Welfare Connection**

Costanza, Pearce, Sutton, De Groot and others argue that resources have value if they demonstrably contribute to increased human welfare. This is true for natural assets including forests, fossil fuel deposits and clean water supplies. Many environmental assets more effectively contribute to welfare for longer periods of time if they are utilised in a sustainable and non-destructive way. Rees (1998) questions the reliance of decision-makers on flawed assessments of market behaviour such as GDP, stating that "the contributions of nature… are not presently well-represented in markets and are therefore given too little weight in policy decisions".

U.S. National Income and Product Accounts (NIPA) are used by government officials and policy-makers to provide a "full and comprehensive picture of the nation's economy" and to gauge and model the effect of "national taxes, regulations and consumption patterns". NIPA approaches are asymmetrical and do not consider services and goods withdrawn from wild nature. Nordhaus and Kokkelenberg (1999) note that integration of natural stocks with NIPA reporting strategy will be challenging and recommend a phased approach. Integration involves "resolving major conceptual issues, developing appropriate physical measures, and valuing the relevant flows and stocks." The effect of such procedural changes would be wide-ranging: extrapolations of the size of missing natural capital markets reach US $34 trillion per year, a value 83 per cent higher than Gross World Product (Costanza et al. 1997). Costanza concludes that "although ecosystem valuation is fraught with difficulties and uncertainties, one choice we do *not* have is whether or not to do it" (my italics).

Conservationist policy demands information sources that reflect the true environmental cost of various scenarios through the mechanism of environmental auditing. "Decisions about conservation or restoration can lead to the misuse of resources when not guided by some concept of value" (Howarth and Farber 2002). Lack of information regarding the market influence of intangible natural assets brings about under-provision, misuse and inadequate or unfair policy weighting. Gustavson et al. (2002) warn that "values perceived by humans and the preferences expressed in the market system, or through other monetary valuation, may not take into account what is necessary or relevant for ecosystem integrity for the maintenance of natural ecosystems and associated services".

Investigations of total economic value (TEV) indicate that sustainable management and exploitation can yield more value than destructive harvesting. Kumari (1994, cited by Balmford et al. 2002) compares economic contributions of high-intensity logging and harvesting with new approaches of reduced-impact logging in Malaysia. When non-tree forest products, flood protection issues and biodiversity stocks were considered, the forest total TEV was 14 per cent higher under sustainable management. The private benefit to loggers was slightly reduced but this was more than offset by retained social and global benefits. Short-term individual-scale market economics do not make global public-good activities seem worthwhile – the result of half a century of policy which neglects so-called 'free gifts' from nature (Bureau of Economic Analysis 1994, Costanza et al. 1997). Symmetrical accounting and policy aimed at sustainable development may contribute to more balanced private benefits in future.

3.2.1.5. **Recommendations and Next Steps**

There is little consistency of classification approach or methodology within academic literature in environmental economics. This makes it difficult to identify a single strategy for natural asset inclusion in macro-accounting (Norgaard 1989, De Groot et al. 2002, Gustavson et al. 2002). Using traditional data-capture approaches it is difficult to fulfil the information requirements of increased ecosystem management, policy and regulation. Without referring directly to Earth Observation, Gustavson et al. (2002) call for "a general proxy measure of functional characteristics within a community which is supported by theory, calculable using a limited dataset and information base, and applicable to a wide variety of ecosystems". Problems of data capture and format limit interaction modelling between ecological conservation and global economics. Large scale monitoring of many variables and proxies is required for accurate estimations, yet traditional means of field data-collection are inadequate. Balmford et al. (2002) state that "although limited data make the [modelled] answer imprecise, they indicate that conservation...represents a strikingly good bargain". This is consistent with the findings of Stern (2006), Costanza et al. (1997) and others.

To offset under-representation of environmental assets in accounting procedures and as a framework to support national responses to environmental taxation, Global Environmental Markets (GEMs) have been developed and widely advocated (Pearce 1995, European Union Greenhouse Gas Emission Trading Scheme (EU ETS) 2005, International Emissions Trading Association 2006). Incremental efficiency savings and new technology adoption (gas and nuclear power stations and the introduction of unleaded fuel) yield large returns in emission abatement. These initial steps have already been implemented in many developed nations due to clean air and water legislation and growing public opposition to polluting industrial practices. To achieve national targets in carbon accounts, developed nations must invest heavily in new approaches, which are more expensive than established technology. GEMs circumvent this problem by providing a carbon-trading protocol. Pearce (1995) states that "the essence of the concept is that country A secures a benefit by reducing emissions or undertaking conservation in country B". Pearce continues to explain that through hypothecation in Norway, the proceeds of domestic carbon taxation are directly invested in reducing carbon emissions in Mexico by providing energy-efficient lighting. Under the same scheme, coal-fired power stations in Poland have been replaced with more modern gas-fired equivalents. For the same investment, greater atmospheric carbon emission reduction can be achieved in developing nations than in Norway. Stern (2006) suggests that global economies will be affected by climate change and environmental degradation and it is likely that environmental accounts, emissions trading and other GEM initiatives will become more relevant in coming decades.

3.2.2. Economic Components

3.2.2.1. Information Markets

At the dawn of the 21st Century the world is witnessing a new reality – a reality where the commercial uses of space far outpace military uses and are close to surpassing all government space activities (US Department of Commerce 2002).

Sale of environmental data takes place within the context of a rapidly changing 'information society'. For many users "recent rapid advances in technology, data handling, and data transmission mean that many data formerly too expensive are now available at prices that directly compete with the costs of data from more conventional sources" (Moorman 1998, Millard et al. 1998). The task of environmental data capture is linked to concepts of environmental service valuation and environmental accounting because 'data drought' is commonly a limiting factor in modelling and resource assessment (Gustavson et al. 2002, Balmford et al. 2002). Millard et al. (1998) note the interlinking of environmental valuation and data: "whether environmental data can be valued financially raises the question as to whether the environment itself can be valued financially." Emerging requirements for large-scale data collection, collation and processing, necessary for the fulfilment of international legislative obligations drive market development and reinforce the decision-support potential for many geospatial datasets. Increased market penetration may lead to more rapid, responsive and user-led product development; something that has seemed elusive to some Earth Observation customers (Woodhouse 2004, personal communication).

3.2.2.2. Market Size

Despite considerable investment in space science in recent years, and the resulting growth of the space industry, the US Department of Commerce (USDC) states that "we know less about the space industry than we do about other sectors of the US economy" (Hertzfeld 2001). The USDC investigation of space sector investment and growth followed urgent requests from government and private sector officials for support from the space sector. They "called for better planning and policy tools that require better, more comprehensive, more consistent, and more uniform data." USDC concludes that new methods of reporting on the space sector are required and that "it is time to devote serious effort to improving space economic data" (Hertzfeld 2001). Prior to USDC investigations, European Commission (EC) funded research under the Envaldat programme (Millard et al. 1998) aimed to answer similar questions: how is it possible for non-specialists to assign dollar-values to data worth in the environmental sector? Without a standardised valuation approach the justification of data purchase or costly direct acquisition posed challenges, especially when competing methodologies were subject to established costing procedures (Millard et al. 1998).

Envaldat conclusions are broadly consistent with USDC findings. One key barrier which limits data sales and integration is poor availability of tools for evaluating usefulness, appropriateness and cost-effectiveness among the user community. The data market is poorly defined and supply entities do not invest in discovering the needs of their clients through market research. Millard et al. (1998) consider that development is hampered by historical dominance of public-sector agencies in data collection and use (due to the very high cost of data capture), which has led to a supply-led and non-responsive market. This can seem frustrating and illogical to new users who may not possess the technical keys required to process data; because of this, a so-called "knowledge gap" emerges.

The information marketplace is young and developing rapidly, so a growing requirement exists for the provision of tools and approaches to assist policy-makers and managers in deciding whether to implement data-dependent new procedures. Alongside uptake issues, the following problems consistently occur in the data market (Millard et al. 1998).

- There is little user feedback regarding usefulness of data
- Data assessability is poor and clearer archiving is required
- Data accessibility is poor, so it is difficult to locate and obtain data
- Public policy is inconsistent with regard to secondary data use
- Data Policies are inconsistent in coverage and application

3.2.2.3. **Assessing Performance**

The global institutional investment in civil space activities is around €25.9 billion per year, of which the European share is around €5.7 billion (European Space Agency 2002, 2005). Grant and Keohane (2002) find that although significant civil and private-sector economic investment occurs in space markets, national commitments are very uneven. The USA dominates public space expenditure, with an annual budget of around €16.2 billion. Further to this, US budgets account for 95 per cent of global military spending on space. This is partly attributable to ESA founding principles, which preclude aggressive military use, so a more commercial focus is reflected in spending balance: 91 per cent of European investment is in the civil sector. In fact, ESA policy statements reflect an appreciation of non-market components of value, stating "budget and employment figures are objective criteria for comparison, but they are not enough for providing a complete assessment of the space sector" (ESA 2002). The ESA position on Earth Observation was further strengthened in 2004 with the following statement.

> Earth Observation from space can support sound environmental management and protection by providing basic, homogeneous observations with unsurpassed coverage on climate and weather, oceans, fisheries, land and vegetation. Therefore, Earth Observation satellites are a key means of sustainable development goals (European Space Agency 2004).

In terms of commercial market development, ESA (2002, 2004, 2005) recognises three key areas: telecommunications, Earth Observation and navigation and positioning. Since 2000, commercial turnover of European space industry has declined to levels lower than those achieved in 1995 and 1996, illustrated Figure 3.1.

The majority of decline has been experienced in telecommunications markets, because shifts to digital transmission and improvements in compression technology have reduced consumer bandwidth demand, leading to network over-capacity. Figure 3.2, showing space segment expenditure for 2001 and 2002, shows the stable relationship between telecommunications and Earth Observation spending. Earth Observation space segment activities are about two-thirds of the size of those in the communications sector. However, a comparison of value-adding revenue reveals inequalities spanning an order of magnitude; telecommunications revenue for 2002 was €90 billion, but for the same period Earth Observation generated €4 billion.

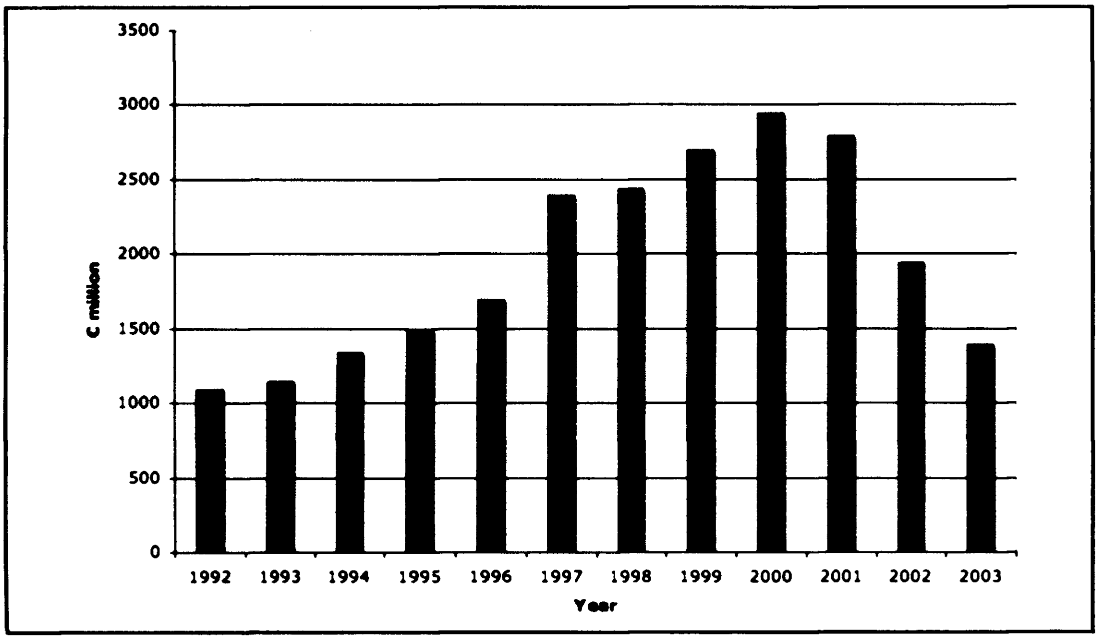

Figure 3.1 European commercial space industry turnover, 1992-2003 (European Space Agency 2005).

Over half of Earth Observation segment-share is attributed to public-sector activities, leaving a commercial data market which represents 8 per cent of satellite activities, equivalent to €480 million per year (ESA 2002). To explain the low sales volume and poor value-adding performance, Euroconsult state that "as far as Earth Observation is concerned, there is almost no commercial potential since one of its major services, meteorology, doesn't have a commercial value although it does bring strong benefits to the socio-economy of Europe" (ESA 2002). One reason for limited commercial development is that meteorology is supported by civil spending, and "public agencies or organisations are providing information on a non-commercial base to various users" (ESA 2002). Meteorological applications accounted for 11.6% of European civil space budget in 2001, when the share of Earth Observation was 12.2% (ESA 2002). Closer examination of Earth Observation and telecommunications value-chains is required (Figure 3.3).

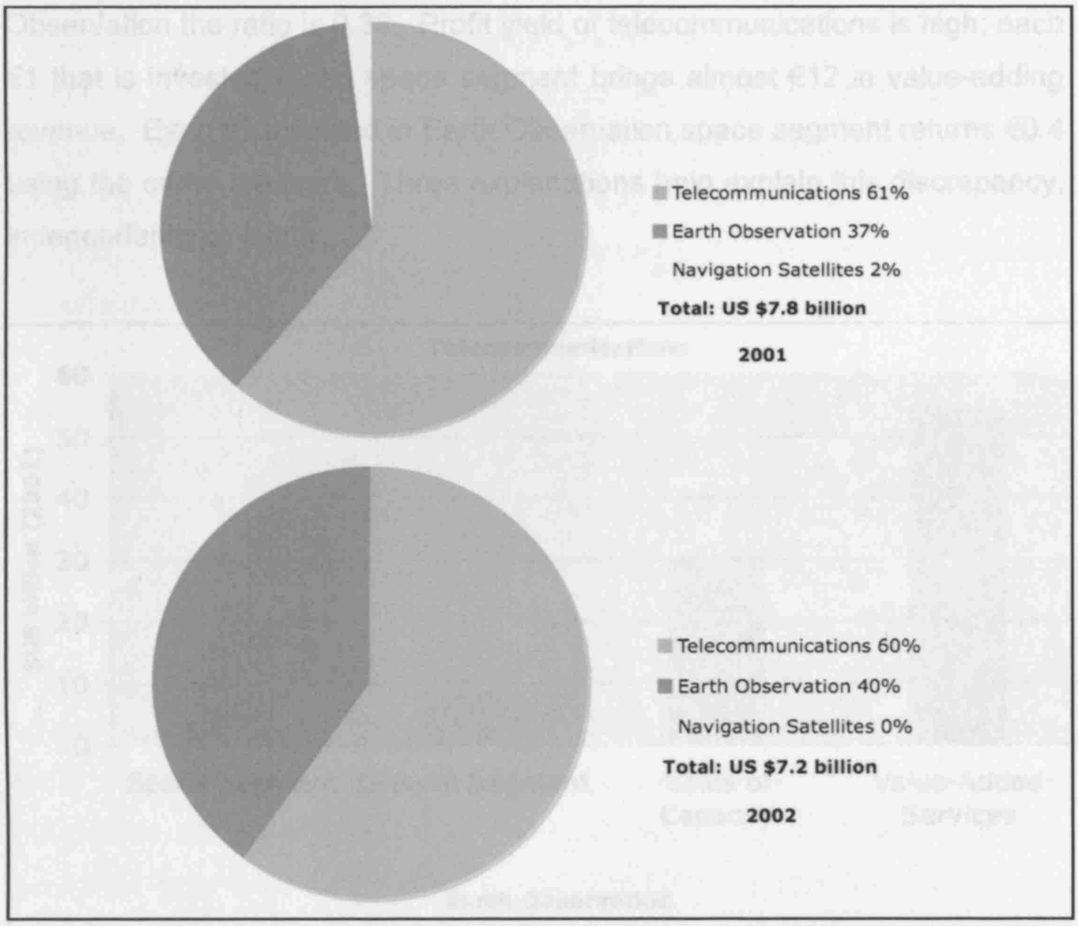

Figure 3.2 Space segment expenditure for commercial satellite operations for 2001 and 2002. No spending was recorded for navigation and positioning in 2002 (ESA 2002, 2004).

There is no evidence that Earth Observation and telecommunications are equally profitable so magnitudes of markets and expenditure reveal little. Comparisons focus on ratios of return-on-investment. For each € invested in orbiting infrastructure, it is possible to calculate the profit from derivative value-added services. Value-added services commonly involve the investment of expertise, intellectual capital or technical processing to enhance a basic product (as for Precision Agriculture). Sometimes a franchised capacity reselling structure is used, as in the case of consumer Broadband. If equal levels of market development and penetration were achieved, ratios of value-adding activity to space segment expenditure would be equal. for telecommunications this ratio is 11.64, whereas for Earth Observation the ratio is 0.38. Profit yield of telecommunications is high; each €1 that is invested in the space segment brings almost €12 in value-adding revenue. Each €1 invested in Earth Observation space segment returns €0.4 using the same measure. Three explanations help explain this discrepancy, independently or jointly.

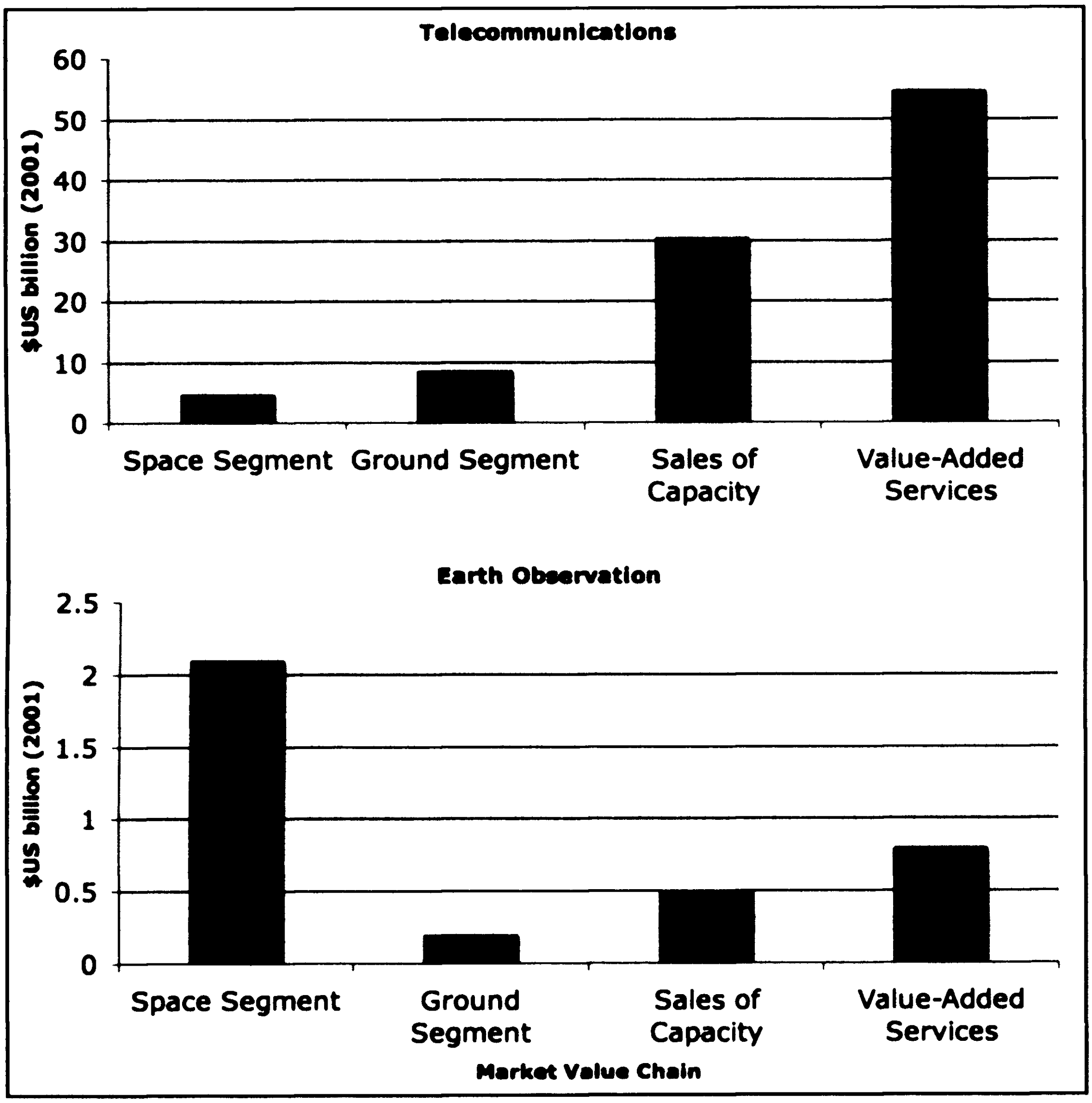

Figure 3.3 Spending and revenue balance in Earth Observation and telecommunications for 2001, illustrating large Earth Observation space

segment costs which are not offset by strong value-adding performance, as they are in the telecommunications sector (ESA 2002).

The first is that telecommunications are more closely integrated with consumer spending through the expansion of broadband and satellite television. This is supported by relatively strong satellite capacity sales in the sector (€6.73 billion per year, compared with €0.15 billion per year for Earth Observation). With the exception of weather information and consumer mapping, Earth Observation has not achieved the same degree of market penetration.

The second issue concerns market development, which has been very successful in telecommunications and which enables large revenue generation through the value-adding and satellite capacity sectors (Figure 3.4 and 3.5). Return-on-investment is achieved through growth in sales volume and transaction size, and protected through licensing, bandwidth sales and engineered excludability (through digital 'keys' such as smartcards). As discussed in later chapters, market development activities in Earth Observation have been hampered by unresponsive value-adding companies and poor marketing. Historical overselling to a weary consumer base has negatively affected uptake; Fuller (2000) states that "one of the problems with remote sensing is that it can be over-promoted as a cure-all".

Finally, non-market components make up a very small proportion of telecommunication transactions. It is proposed that such goods and services are very significant – perhaps the dominant influence – in Earth Observation data exploitation. The European Space Agency addresses non-market value; "the impact of space activities extends far beyond the economic activity generated in terms of employment and revenue ... it is increasingly seen to deliver a wide range of socioeconomic and strategic benefits ... to the social wellbeing of a society" (ESA 2004).

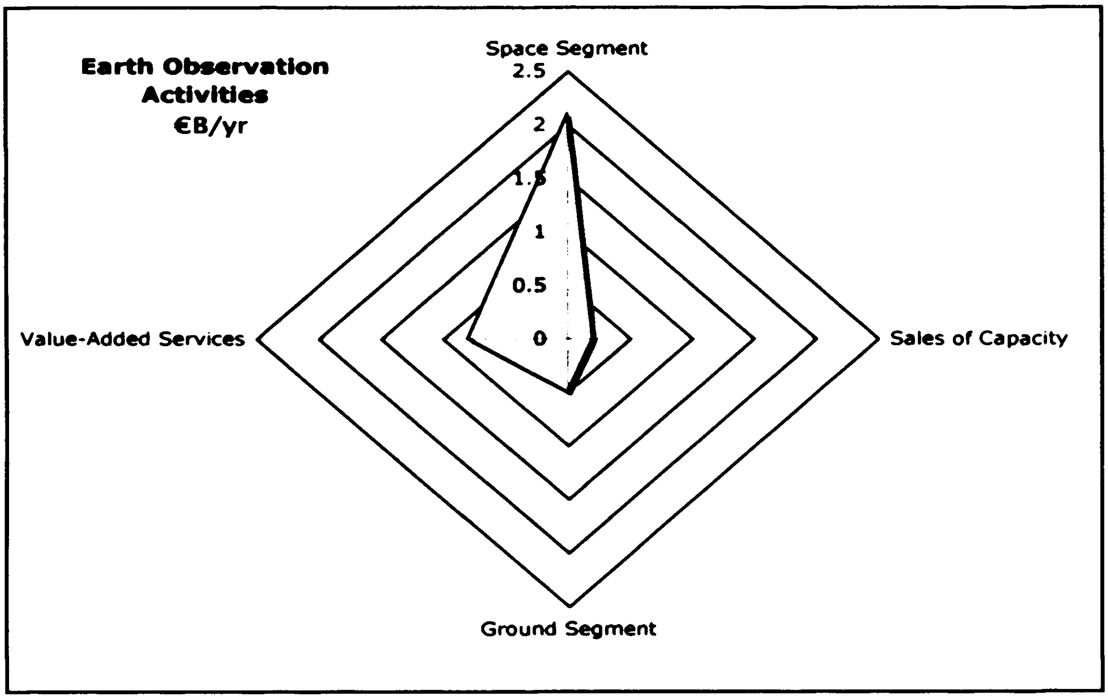

Figure 3.4 Balance of investment in Earth Observation activities, showing large Space Segment and modest value-adding sector performance (ESA 2002)

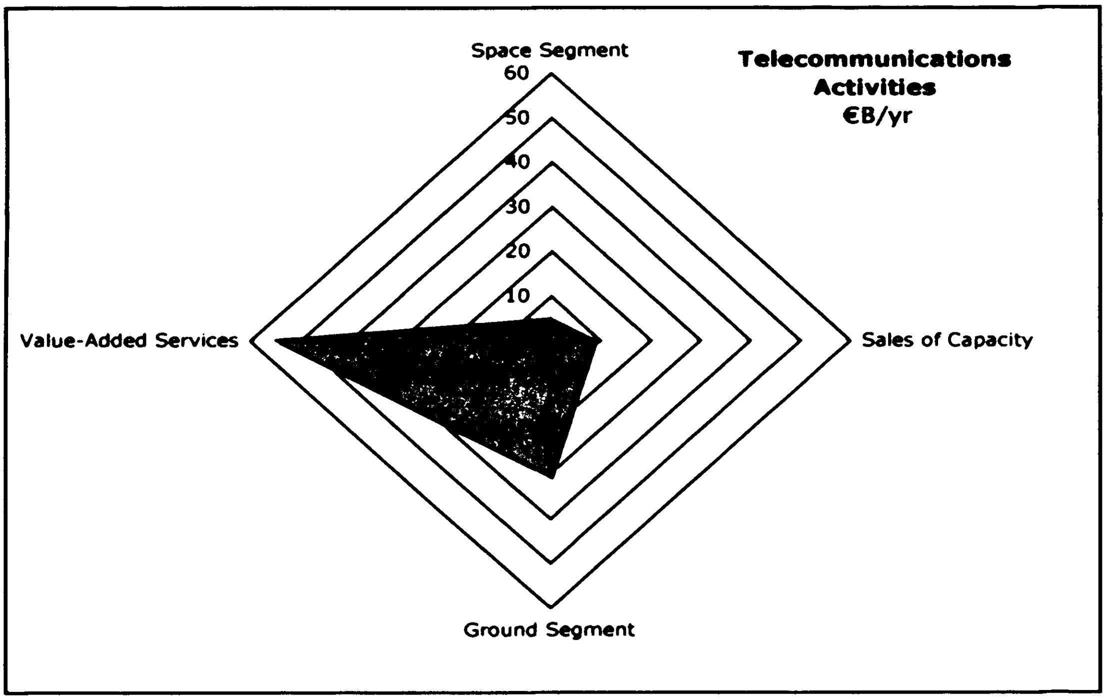

Figure 3.5 Balance of investment in Telecommunications. The chart shows the strong performance of value-adding activities. Chart axes are not the same scale (ESA 2002).

3.2.2.4. **Satellite Case Study**

Although Figures 3.2 and 3.3 illustrate the relatively modest commercial achievement of the Earth Observation sector, several European satellite programs have been individually successful in recent years. ERS-1 (Earth Resources Satellite 1) was conceived as an almost exclusively scientific mission with little or no commercial payload. Commercial distribution of data products was not even added to the mission objectives until after launch (Kohlhammer 2001). Despite this, over 72,000 synthetic aperture radar (SAR) data products had been sold by the beginning of 2001 to a customer base of 3,500 scientists and other users.

Building on the limited successes of the 1991 ERS data policy, a revised ENVISAT document was issued in 1998 to set prices for data. A brief summary of data types and prices is set out in Table 3.1, and a detailed discussion of data provision and policy can be found in chapter four. Prices of commercial satellite data incorporate profit margins which reflect investment of intellectual capital and processing time, and scientific users are charged a marginal rate to account for costs of fulfilling user requests. Prices were initially too high for the scientific community and sales of research data were slow, so these users accounted for less than three per cent of sales in 1992. Later pricing schemes under the 1998 policy incorporated reduced costs for scientific research because it was acknowledged that price-based exclusion of users, with data administered as a quasi-private good, limited avenues of exploitation that could yield significant non-market and societal benefits. The response – provision of data to qualified users free of charge through special programmes – recognises Merit Good provision (discussed in chapter four of this thesis) as a valid supply strategy to protect and ensure delivery of non-market benefits.

Table 3.1 Pricing structure for ERS data products (Kohlhammer 2001).

Description	Commercial Price (€)	Research Price (€)
Fast-Delivery Image	500	200
Annotated Raw Data	1,000	200
Reduced-Res Scene	250	125
Single Look Complex	1,200	500
SAR Precision	1,200	300
SAR Geo-coded	1,400	500
SAR Terrain Geo-coded	2,300	1,000
Educational	90	90

Reflecting an acceptance of the needs of the scientific community, a data policy supporting Merit Good provision applies to the US Landsat programme (section 4.3.1.2). Although some characteristics of Landsat data justify its provision by government, this provision was not always available. More complete recovery of investment was sought in the early 1980s. US policy makers discussed mechanisms for dealing with a severe revenue shortfall caused by the funding burden of spaceborne remote sensing, with particular reference to the Landsat programme. Such discussions were part of a wider political movement, motivated by budgetary constraints, towards reducing direct costs by commercialising government functions. For Landsat the change to commercial management was formalised in 1984 by public law PL 98-365, which "established a process for commercialising Landsat and licensing private land remote sensing satellites" (Johnston and Cordes 2003). The accompanying Presidential Directive calls for NOAA to "seek ways to further private sector opportunities in civil land remote sensing activities ... with the goal of eventual operations of these activities [wholly] by the private sector" (PDD 54, July 1979, cited by Florini and Dehqanzada 1999).

At the time of commercialisation, Landsat 4 represented the most advanced civil Earth observation sensor, but its situation within US government structure was uncertain. Between 1978 and 1985, it was unclear whether National Oceanographic and Atmospheric Administration (NOAA) would remain part of the US Department of Commerce (DOC), or whether it would be subsumed by new departments focussed on Science or Natural Resources. In addition to this organisational uncertainty, NOAA had a demanding commitment to the management of polar-orbiting satellites including AVHRR. Johnston and Cordes (2003) note that "a land remote sensing system was not particularly of interest ...[so] Landsat did not receive high priority within NOAA".

Unease regarding Landsat commercialisation intensified during the Reagan presidency, culminating in a DOC study, delivered in 1983. The work concluded that there was no option for commercialising the Landsat programme without significant government subsidy, despite pricing that was already set well above the cost of fulfilling user requests (see Marginal Pricing, Table 4.3). Three further studies agreed; the market was immature and commercialisation represented "forced premature privatization of [national security] responsibilities" (National Academy of Public Administration 1983, cited by Florini and Dehqanzada 1999). During the same period, some discussion of value-types occurred, through which US weather satellites were defined as "essential public goods that must be provided by the government" (Johnston and Cordes 2003). This categorisation is visited in detail in chapter 4. The objective was a two-tier US remote sensing system comprising a federally funded atmospheric / oceanographic programme operating alongside a commercially self-sustaining land observation platform.

Alongside the DOC study, criticism also came from outside; the shift to commercial provision of Landsat data was not universally supported. As early as 1983, the journal *Science* questioned such measures, stating that "the Reagan administration... may soon find itself setting up something that looks a lot like a government-subsidized Landsat monopoly" (Waldrop 1983, 1987). The journal also interviewed early-adopters of Landsat products for oil and gas exploration, one of whom stated: "if we fail to provide the [Earth Observation] data, France and Japan will step in to fill the gap" (Halbouty, cited by Waldrop 1983).

In the period 1984-1992, cost-based barriers to entry and the existence of a strong government monopoly prevented any applications for commercial remote sensing licences in the US. Operators abroad were making progress. The launch of the French SPOT in 1986 and the Indian IRS-1A in 1988 removed the US monopoly on medium-resolution Earth observation, and compounded problems of poor sales. Commercial Landsat prices had increased by up to 600% by 1984, which led to a substantial reduction in demand.

Over 35,000 orders for Landsat MSS data were received in 1984; in 1990 sales had dropped to 8,000 as users elected to use lower resolution alternatives such as AVHRR or cheaper datasets from SPOT. A multispectral Landsat scene cost US $200 in 1981, but the same scene cost US $730 in 1984 (O'Connor and Collins 1988). The loss of market share was significant, and by 1989, SPOT sold more commercial imagery than the US prime contractor for the Landsat programme (Florini and Dehqanzada 1999).

Stallkamp (2006) comments that following commercialisation the government remained "one of the primary purchasers of the [Landsat] data, now at a much higher rate", a statement echoed by Johnston and Cordes (2003); "the customer base did not grow as expected and the federal government remained the largest customer for Landsat data". Bourbonnière (1996) examines legal elements of Landsat commercialisation, concluding that "the transfer of a monopoly to private space contractors without a recuperation by the American government created a government subsidised industry ... this imperfect market structure can, if improperly supervised, give rise to various types of unfair market practices". Through EOSAT, US industry was subsidised in all but name, in contravention of government policy. This protectionism was unsustainable.

In 1992, public law PL 102-555 (*Land Remote Sensing Policy Act of 1992*) was passed by Congress and the Bush administration, returning the Landsat programme to the federal government. The Act was an acknowledgement that 1984 commercialisation was unsuccessful, and the new policy altered development objectives away from near-term commercialisation. The Act states "despite the success and importance of the Landsat system, funding and organizational uncertainties over the past several years have placed its future in doubt and have jeopardized United States leadership in land remote sensing" (available at http://geo.arc.nasa.gov/sge/landsat/15USCch82.html). A return to federal management allows the collection of long-term global datasets for environmental and global change research and recognises the need to compete with the growing capabilities of European and foreign sensors.

3.2.2.5. **Market Development**

In recent years European economic strategy has been concurrently reassessed with data policy changes. Schleicher-Tappeser (2000) asserts that this reflects "doubts... whether maximising infrastructure and minimising costs is in all cases the best that can be done for economic development". In the context of rapidly increasing demand for information to support decision-making and legislative compliance, and rapid growth in other sectors, operational uptake of Earth Observation data in the UK has been very cautious (Woodhouse 2004, Twigg 2005). In Europe "progress has been extraordinarily slow and industry profitability poor, although value to society has been proved in many areas" (Rosenholm and Harris 2002). "Remote sensing and land cover mapping have their own peculiar economics" (Mitchell 2000), which are inadequately captured by accounting practices which "can't show the value of intangible assets on the balance sheet" (King and Henry 1999).

Poor market penetration has been attributed to lack of accessibility (Millard et al. 1998), but this may not be the key factor. The Earth Observation marketplace is dominated by very few suppliers because cost-of-entry and data capture costs are very high. It is estimated that investments of up to US $497 million are required before any return is made (Mitchell 2000).

Once data acquisition capabilities are established, the core activity is information-trading; although data are a priced commodity, value lies in embedded information. This information has become cheaper as Earth Observation technology and expertise has matured: derivation of basic parameters from early Landsat images cost as much as US $20,000 per scene (including image cost of US $4,000), but the same information is currently available for under US $2,500 per scene, and images are now US $600 each (Mitchell 2000). The suitability of Earth Observation datasets as stand-alone replacements for more traditional approaches has grown with increasing sensor capability, and for some activities remote sensing now represents the least-cost methodology (Table 3.2, Millard et al. 1998, Armstrong 2000).

Table 3.2 Cost of Earth Observation as an alternative data source for coastal management practices (Capes et al. 1998, cited by Millard et al. 1998).

Application Example	Conventional Cost	EO Cost
Mapping and Surveys	€4,500 per km^2	€100 per km^2
Pipeline Routing	€15,000 plus processing	€2,500 plus processing
Geological Structure	€30,000 plus processing	€3,000 plus processing
Ground Subsidence	€10,000 minimum	€1 per km^2

The lag in market maturity, which has not kept pace with technical progress, can be explained by transport infrastructure research which indicates that "improvement in accessibility does not yet lead to economic development in peripheral areas" and furthermore "the issue of material transport - traditional 'infrastructure' - appears strategically much less important than the *exchange of know-how* and the access to innovation-relevant information" (Schleicher-Tappeser 2000, my italics). "For some [Earth Observation] products the market is quite mature. Weather forecasts and topographic maps are two examples of data products that are regularly sold to a consuming public" (Millard et al. 1998). For other products, knowledge gaps prevent potential users from evaluating data: Fuller (2000) states that "there remain problems with both data distribution and the lack of trained imagery analysts to interpret the data". Participating in the same discussion, Thomas (2000) comments "in its outreach programs NASA has found a number of cultural and institutional barriers in the distribution and use of data". Responsiveness was identified as a key concern: "it is essential to understand the needs and concerns of the users and potential users of remotely sensed data. Data providers need to take these trends and priorities into account as they gather data ... it is important to realise that education of the users will take a certain amount of time" (Roeder 2000).

3.2.3. **Law and Enforcement**

3.2.3.1. **Policy**

The launch, operation and management of space-borne Earth Observation systems is governed by a suite of internationally ratified legal instruments, treaties and guidelines, originally compiled following recommendations issued by the World Meteorological Organisation (WMO) and the United Nations (UN). The most notable are the 1986 Principles Relating to Remote Sensing of the Earth, adopted by the UN General Assembly. The principles are available online through the UN Office for Outer Space Affairs (http://www.oosa.unvienna.org/SpaceLaw/rs.html). These comply with and extend pre-existing law, most notably the Outer Space Treaty (1967). Rapid technical development of remote sensing in the last forty years has led to significant step-changes in the nature and volume of data collected. In this light, a review of governing principles is required alongside policy changes to reflect current state of the art (Harris 2003, Rao and Sridhara Murthi 2006). Two components of the original 15 principles are fundamental to the subsequent direction of Earth Observation, and are therefore worthy of review. UN Principle I states that remote sensing should be undertaken "for the purposes of improving natural resource management, land use, and the protection of the environment". Principle II states that "remote sensing shall be carried out for the benefit of and in the interests of all countries, irrespective of their level of economic, social or technological development and taking into particular consideration the needs of the developing countries" (UN 1986, cited by Harris 2003). Further to the recommendations of UN Principles, which are not customary law, WMO guidance notes have been added, including Resolution 40 of 1995 (cited by Harris 2003), which calls for higher levels of information exchange to enable and facilitate more systematic and complete environmental observations.

Maturity of governance in remote sensing and other spaceborne Earth Observation leads to greater integration with local, regional and national policy. International and trans-boundary legislation can be supported by the unique Earth Observation viewpoint and legal position, as set out by "Open Skies" components of the Outer Space Treaty. Most legal interventions contain a spatial component, whether it is proving military incursions, assigning responsibility for effluent plumes or identifying access routes for illegal logging or fly-tipping. So why is it that "though one can consider many examples where Earth Observation data could have justifiably been employed, lawyers, in general, rarely consider it as an option?" (Ainsworth et al. 2001). Statistics confirm this assertion: only four US court cases had presented satellite images as evidence by late 2001 (Ginzky 2001, cited by Karathanassi et el. 2003).

3.2.3.2. **Principles and Law**

For purposes of law enforcement, satellite images are preferable to cartography because scope for generalisation and the introduction of human error is more limited. In the light of increasing reliance on images alone for pure science, large-scale mapping and classification (Armstrong 2000), an image can provide a defensibly impartial snapshot of a location in time and space which can be corroborated using ground-truth data (Hackford 2001). Hackford notes that, although cartographic errors are avoided by using directly-sensed images, interpretation error is still a significant consideration: "for those who are familiar with the images, or who have visited the locations concerned it seems to be very clear and straightforward to interpret the images ... [but] experience shows that *very clear* instructions and guidance needs to be given to judges to enable them to understand the [satellite] images properly". Dehqanzada and Florini (2000) discuss limitations of satellite image interpretation, using military imagery analysis as a case study. The authors warn that "junior analysts are wrong far more often than they are right" and recommend that "imagery analysts go through extensive training not only at the beginning of their careers, but also every time they shift the focus of their work" (Dehqanzada and Florini 2000). Satellite images are gaining currency in legal practice as a cost-effective way of acquiring consistent and representative spatial information. To enable further market development, Ainsworth et al. (2001) recommend two courses of action.

- The universal adoption of approved processing strategies. Rigorous maintenance of audit-trails should be undertaken for all digital images. Standards-compliance data for both processing and audit trails should be available to courts.
- The fulfilment of evidentiary requirements through provision of appropriate expert testimony, "data visualisation and presentation of technical issues" (Ainsworth et al. 2001). Authors note that problems may occur because different judicial bodies have differing stipulations for the presentation and admission of evidence.

Some limitations of traditional surveillance approaches are circumvented by Earth Observation methodologies. The Outer Space Treaty, which states that no sovereign territory stretches beyond the borders of the Earth's atmosphere, ensures that governments and non-governmental entities can monitor activities across borders with impunity and without permission. In this way "the 'Big Brother' role of satellites ...is important for many compliance purposes" (Ainsworth et al. 2001).

In other ways, use of space-borne sensors introduces new problems. Of note are concerns regarding the individual rights to privacy afforded by Article 8 of the European Convention on Human Rights (ECHR), which became UK law in 2000. For the purposes of ECHR, Earth Observation cannot be governed as a form of surveillance alongside closed-circuit television (CCTV) and other public order and security devices, because satellites "cannot be painted yellow like speed cameras, and cannot distinguish between public and private property" (Purdy and Macrory 2003). Even if it is accepted that satellite remote sensing is covert by coincidence and not design, it has been upheld in the English Court of Appeal that "the infringement consists of depriving the person filmed of the possibility of refusing consent" (case of Reg vs. Broadcasting Standards Commission 2000, in Ainsworth et al. 2001). However, the legal weight of personal objections to satellite coverage under ECHR Article 8 is currently insignificant because sensors are not currently capable of isolating and tracing individuals. Issues of privacy will become more relevant with increasing ground pixel resolution.

3.2.3.3. **Intelligence**

Successful launch and operation of very-high-resolution (VHR) optical sensors in the commercial domain changed the legal sphere of influence of Earth Observation. Non-governmental actors and governments with no indigenous satellite technology were able to acquire so-called "spy-satellite" images for the first time, with the capability to discern ground objects as small as 1m in diameter, and linear features much smaller (Bjorgo 1999, Dehquanzada and Florini 2000). For any nation or organisation with sufficient finances, international intelligence collection became an achievable goal almost overnight. The development of VHR optical sensors was driven primarily by technology transfer from the classified domain. Work initially focussed on film cameras and high-altitude aircraft, but legal challenges and the growing threat from late-generation integrated air defence systems altered the balance in favour of spaceborne intelligence collection assets.

Before 1972 and the launch of Landsat 1, spaceborne Earth Observation was confined to arenas of military surveillance and meteorology. The rapid development of civilian and scientific remote sensing sensors and expertise in the wake of Landsat did not motivate a relaxation in reconnaissance data policy, and it was not until 1995 that an Executive Order was signed to allow access to the early US satellite surveillance systems, codenamed Corona, Argon and Lanyard (CIA 2001). It is probable that this was precipitated by the availability in the mid-1990s of declassified very-high resolution Russian surveillance imagery acquired by the Sovinformsputnik agency. The quality and availability of KVR-1000 data, at around 3-4m spatial resolution, was a concern for the US Clinton Administration (Gupta 1995, cited by Bjorgo 1999). Two measures were implemented to protect US satellite remote sensing interests and maintain market share: the 1995 declassification of Corona, Argon and Lanyard programmes (Executive Order 12951) and the 1998 Commercial Space Act (PL 105-303) to encourage government use of commercial data.

To explore the development and funding of spaceborne reconnaissance, it is useful to discuss the political landscape of the US in the late 1950s. Public concern focused on Russian military and technological development, especially concerning long-range strategic bombers, intercontinental ballistic missiles and the space programme. US anxiety was exacerbated by the 1957 launch of the satellite Sputnik, during a period when "facts were scarce and fears were rampant" (CIA 2001). Declassified CIA documents state that "the Soviet Union was a dangerous opponent that appeared to be moving inexorably toward a position of military parity with the United States... particularly alarming was Soviet progress in the area of nuclear weapons. In the late summer of 1949 the Soviet Union had detonated an atomic bomb nearly three years sooner than US experts had predicted" (CIA 2001).

The US surveillance strategy for Russia relied on outdated and incomplete information, which suggested that Russian radars and air defence systems would be unable to reliably track the U-2 aircraft (CIA 2001). Operating procedures remained unchanged despite a 1956 Office of Scientific Intelligence study, which concluded that "maximum Soviet detection ranges against the ... would vary from 20 to 150 miles [and] detection can therefore be assumed" (OSI, cited by CIA 2001). In fact, pressure to intensify the U-2 programme increased in 1955, when open source reporting from air shows indicated the presence of thirty new 'Bison' long-range strategic bombers. Subsequent intelligence revealed that it was the same formation of ten aircraft performing multiple passes. It became apparent by July 1956 that Soviet systems could successfully track U-2, but that interceptor aircraft could not reach the operational altitude necessary to engage (69,000ft). The same was not true of Soviet surface-air missile (SAM) systems.

Evidence from U-2 crashes in the US indicated that the aerodynamics of the craft led to a classical flat spin in the event of many failures, not the total disintegration predicted by CIA and USAF developers. This reduced ground impact speed considerably, and increased the risk of aircraft identification or reconstruction by hostile forces following aircraft malfunction or disablement.

A meeting was held on 15 November 1956, aiming to restrict U-2 flights to border regions and limited areas of Eastern Europe, in order to limit the potential diplomatic consequences of a crash or aircraft compromise in denied airspace. The position of the US Government was weak because the overflight policy contravened international law and had already provoked official objections from several Warsaw Pact nations. During a meeting in June 1956, Soviet Party Chairman Khrushchev had already warned a US delegation that Russia would "shoot down uninvited guests ... they [U-2 and Canberra reconnaissance aircraft] are flying coffins ... we are making missiles like we make sausages" (Studies in Intelligence, cited by CIA 2004). Herbert Hoover Jr. (acting US Secretary of State) commented "if we lost a plane at this stage it would be almost catastrophic" (CIA 2001).

On 1 May 1960, Hoover's fears were confirmed when a pair of Russian SA-2 GUIDELINE[1] surface to air missiles successfully intercepted a U-2 aircraft. Following the engagement, which resulted in the capture and trial of pilot Francis Gary Powers, it became unacceptable to over-fly denied Russian airspace for reconnaissance purposes. The vulnerability of air-breathing surveillance assets was reinforced by the destruction in October 1962 of a U-2 during the Cuban Missile Crisis. The pilot was fatally wounded, and the

1 The engagement ceiling and maximum velocity of the SA-2 was much improved over previous Warsaw Pact SAM systems; the weapon was effective to 82,000ft and 1,500kph (approximately 930mph) (Studies in Intelligence cited by CIA 2004)

event almost caused a US military retaliation; it was clear to both sides that a significant escalation had been narrowly avoided (CIA 2004)

The legality and cost-benefit of U-2 flights was under question, so in 1958 President Eisenhower approved a highly classified programme codenamed Corona. The aim was to develop satellite platforms to photograph selected foreign sites and address intelligence gaps regarding the development of missiles, submarines and other equipment. One of the key attractions of the satellite programme was the legality of this approach, which involved no contravention of airspace. In addition to legal arguments, space-borne platforms were considered much less detectable than air-breathing assets, and no personnel would be at risk. Just 110 days after the capture of Gary Powers, the first film capsule was recovered from the Corona programme – it was a poor quality depiction of Mys Schmidta, a military airfield in north-eastern Russia. By the time the programme was concluded in May 1972 (to be replaced by more advanced systems), 144 satellites had been launched of which 102 had returned useable data (Studeman 1995, CIA 2004).

The timely acquisition of remotely-sensed data through Corona, Argon and Lanyard supported peace negotiations, and contributed to the end of the Cold War arms race. Space-based surveillance also helped to verify and validate disarmament under the Nuclear Non-Proliferation Treaty, in Russia and beyond. In addition to the intelligence impact of the programme, Corona provided a valuable classified test-bed for orbital dynamics modelling, spacecraft operations and recovery, and electro-optical remote sensing.

The legal admissibility of satellite data has been proven through its use as evidence in several conflicts. In August 1995, US satellite data covering the Bosnian town of Srebrenica was employed by UN Ambassador Madeleine Albright to reveal humanitarian atrocities and newly-dug mass graves. The information was used to support calls for a greater peace-keeping force in the region. When hostilities ceased, war crimes investigators exhumed dozens of executed Bosnian Muslims from the area (Dehquanzada and Florini 2000). Further revelations became apparent in the 1999 Kosovan

Crisis when “the flood of spy satellite imagery made available to the public… was unprecedented” (Dehquanzada and Florini 2000), and during the course of the Iraq conflict, when Ikonos images were extensively used for damage estimation and bombardment monitoring. During the two Gulf Wars and the ensuing conflict, many surveillance images, which had already been prepared for presentation to the UN Security Council, were declassified by the UK Government to influence public opinion and provide intelligence-based justification for ongoing intervention (Figures 3.6 and 3.7). This culminated with the public release of an illustrated Iraq dossier published by the UK Government (HMSO 2003).

Although some military surveillance data has been degraded to reduce classification, in other cases releasable unclassified data has been purchased commercially (Russian KVR data, Quickbird and IKONOS). Such products have been released to the public and distributed with imagery and geospatial intelligence products among multi-national coalition forces in areas such as Afghanistan, Iraq, DR Congo and Sudan.

Figure 3.6 Interpreted satellite image showing the Al-Rafah Shahiyat liquid propellant missile engine test facility in Iraq. Construction work, as at label A, was monitored by UN inspectors who were guided by images of this kind (HMSO 2003).

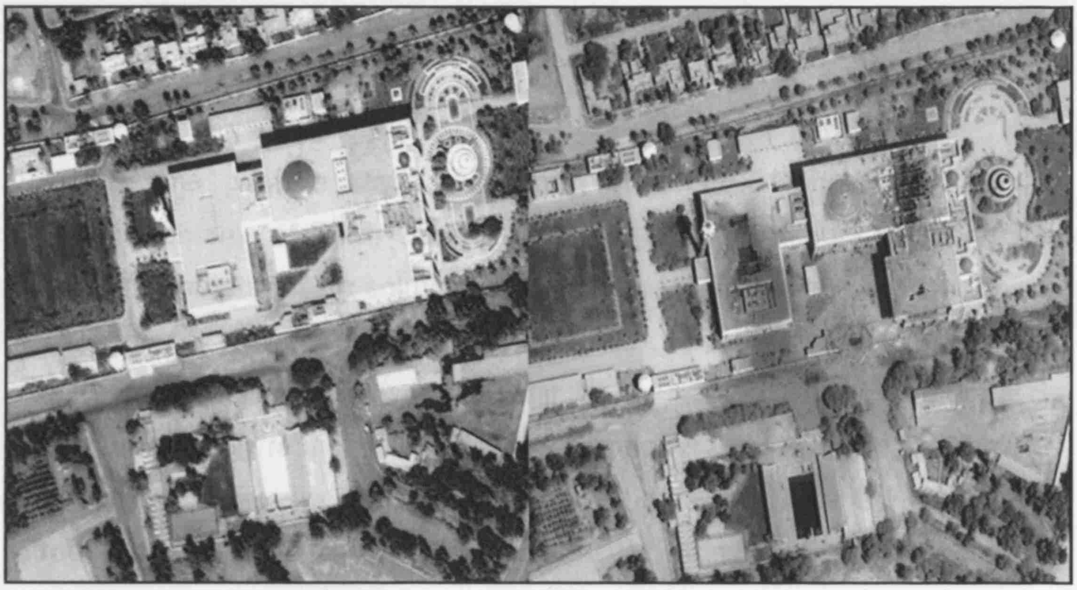

Figure 3.7 IKONOS image showing Presidential Palace in Baghdad, before (left) and after (right) bombardment during Operation Iraqi Freedom, widely known as the Second Gulf War (© spaceimaging.com)

3.2.3.4. Compliance and Enforcement

Satellite data are used for international policy and treaty compliance monitoring in the public domain. The publication of images provides irrefutable data with contents that are hard to diminish or obscure with propaganda. In April 2006, *The Guardian* newspaper stated that "concern over Iran's nuclear intentions was heightened yesterday with the publication of new satellite photographs of its uranium conversion plants …and uranium enrichment complex …showing evidence of new tunnels and facilities". The report continues;

> "the satellite images were analysed by the Institute for Science and International Security, an independent nuclear watchdog group …'they seem to be burrowing away like crazy' said its president, David Albright … 'they have so many underground sites now, you don't know what to hit'" (*The Guardian* 2006).

Media use of satellite data for high-impact illustrations spreads awareness of activities normally hidden from view, but the data also have great potential as environmental and regulatory tools. Quantitative supporting information builds a valid and enforceable threat of legal action against individuals, administrations or nations.

Despite some positive steps, Ainsworth et al. (2001) draw attention to potential problems of Earth Observation data use in the legal sector. Initial testing of remote sensing solutions to planning law in Greece have not been entirely successful (Karathanassi et al. 2003). Purdy and Macrory (2003) note "satellite law enforcement is still in its infancy, but its potential is increasingly being realised". Following a suitable European or English test case, large quantities of high quality archived data may raise the question of retrospective punitive or reparative action for past legal or environmental infractions.

Acceptance of space-based surveillance data in the public domain was not immediate and has been hampered by extensive government use of classified or uncredited sensors allied to continuing mystique surrounding true operational capability. Purdy and Macrory (2003) state that "given the nature of the new technology, it was hardly surprising that some sections of the media expressed cynicism about their reliability as evidence". In some areas of law, Earth Observation data sources can be expected to shift from secondary or corroborative to primary evidence, depending on three factors. First is the acknowledgement of a large potential market among law-makers, defence lawyers and other legal clients by the Earth Observation industry. Second is the acceptance that standards to dictate data handling must be in place to ensure admissibility, and maintain legally-sound audit trails allied to expert testimony. Finally "it is crucial to avoid the suspicion and cynicism that the satellite images in the UK Dossier [on Iraq] received" (Purdy and Macrory 2003), to enable objective and comparative evaluation of benefits attributable to the satellite viewpoint.

3.2.3.5. **UK Implementation**

Problems associated with the use of satellite images in law courts and legislative proceedings are analogous to the development of legal infrastructure surrounding the use of automatic enforcement cameras in the UK. Convention aside, remote sensing can include such sensors if defined broadly as "the science of extracting information from an object or area through the analysis of data acquired by a sensor that is not in direct contact with that area" (Ainsworth et al. 2003). Up to 4.2 million closed-circuit television cameras and 5,000 speed-detection cameras are operational in the UK, and citizens are filmed up to 300 times per day (Murakami-Wood 2006). Use of remotely-sensing devices is a growing trend in UK law enforcement, and "Police have routinely praised the use of ...cameras. They believe criminals are more likely to plead guilty when faced by the undeniable evidence of being caught on camera" (BBC 2006). Across Europe the uptake of digital camera-based traffic enforcement has been so rapid that German researchers commented "we expect that digital cameras will very soon be the first choice for nearly every user of traffic enforcement systems" (Jäger et al. 2005).

Where speed measurement and data capture devices such as Automatic Number Plate Recognition (ANPR) are used for conviction, sensors must meet standards of accuracy, calibration and reliability set down by the Secretary of State. These 'type-approval' requirements ensure that data are secure, uncompromised, consistent and representative. Such safeguards mean that data can be successfully presented as evidence. Remote detection of infringements of traffic law is desirable because large aerial coverage can be achieved using many low-cost, unmanned sensors. Detectors can be sited in inaccessible, hazardous or inconvenient areas; for example inside tunnels, and enable continuous monitoring (Jäger et al 2005). In this way the justifications for traffic remote sensing are very similar to those supporting remote sensing in general (see, for example, Lillesand and Kiefer 1987, Campbell 1996).

Similarities in sensing technologies refute claims of Purdy and Macrory (2003) that "legislators in this country are unlikely to accept [satellite data]... until the technology is shown to be nearly foolproof and the margin of error extremely low". If a mechanism and legal infrastructure can be designed to penalise motorists using automated digital remote sensors, then it is likely that the same legal instruments can be adapted to penalise farmers who abuse set-aside policy, perpetrators of illegal logging, or ship owners who purge diesel tanks in international waters. The Road Traffic Act (1991) allows type-approved digital sensor images as evidence to support the contention that an offence has been committed. New guidance is required to assist the development of 'protected' Earth Observation images which cannot be altered after acquisition (Jäger et al. 2005), and to establish data in law. Necessary amendments may comprise little more than additions to existing guidelines which control the manipulation of digital photography for use in court, and the storage, processing and retrieval of digital evidence (BSI 1996).

In most cases, the presenting party must be equipped to supply "further evidence that the [images]... came from the original data and had not been mistakenly or maliciously changed in a way that could affect its probity" (Purdy and Macrory 2003). In any case, traffic enforcement is not the only exemplary arena which can inform increased use of Earth Observation in law. Widespread adoption of digital scene-of-crime and autopsy photography means that courts rarely see original film negatives. Staggs (2001) asserts "the party attempting to admit the photograph into evidence must be prepared to offer testimony that the image is an accurate representation of a scene" – a feat only possible using remote sensing if other images, acquired at different times from the same or other sensors, depict similar landscape features with the exception of the relevant area of interest or crime scene. Even image processing results have been used as evidence in US law, described as "readily accepted practice in which no new information was added to the image" (case of State of California vs. Philip Lee Jackson 1995, cited by Staggs 2001).

3.2.4. **Categories of Value Conclusions**

Environmental Accounting, economics and legal activities provide useful analogues to influence the design of mechanisms to capture the value of Earth Observation data. Accountants acknowledge that pricing the environment is challenging and controversial. It is also necessary for two reasons. Firstly, prices provide regulatory frameworks and allow monitoring of consumption patterns. For scarce or valuable resources, prices can be used as an exclusion mechanism to manage demand and ensure that perpetrators of damaging or unsustainable activities are regulated through price-based recovery of mitigation costs. Secondly, the imposition of costs stimulates discussion of value. It is misleading to create income by withdrawing and commoditising assets from nature (Bureau of Economic Accounts 1994, Nordhaus and Kokkelenberg 1999). This occurs when market benefits are received without taking non-market costs into account. For example, the market revenue of commercial tree felling does not include social costs resulting from reduced woodland area for recreation and carbon sequestration. For Earth Observation the asymmetry is not so clear, but images contribute to decision-making without passing through markets, by improving information. Although there is value in this contribution, its source cannot be acknowledged by examining traditional accounts.

Pricing policies alone do not offer adequate insights into total value because some information users rely on information provision outside markets. Further discussion of issues of exclusion, data pricing and licensing are included in chapter 4. Informative parallels exist between environmental accounting activities and Earth Observation data policy; in both fields significant components of total value are excluded from market activities. Proving the value of goods which have no market presence is important to ensure they are sustainably managed and that their influence is properly considered in policy decisions. It is also prudent to acknowledge non-market value to check that future provision of goods and services is not jeopardised by mismanagement. In Earth Observation, just as for environmental accountants, tools for assessing non-market value are required to supplement economic data.

The economic impact of space is poorly understood. The capabilities of Earth Observation data have changed rapidly with increases in technical ability. Reporting frameworks are no longer capable of delivering accurate insights and new approaches are urgently required (Moorman 1998, Millard et al. 1998, US Department of Commerce 2001). Hertzfeld (2001) asserts that space economic data lags behind other sectors because tools for adequately measuring progress and market growth do not exist.

A review of European Space Agency figures suggests that space is worth around €209 billion per year globally. Earth Observation and telecommunications dominate civil space activities; it is informative to compare the market performance of these sectors. Figure 3.3 shows the relatively small markets and high costs associated with remote sensing. The picture is clearer when normalised returns are compared; each Euro invested in Earth Observation space and ground segment activities brings €0.4 in value-adding revenue, yet the same measure applied to telecommunications gives a revenue of €12. In addition, the market for reselling telecommunication satellite capacity is almost 45 times larger than the capacity market in Earth Observation (ESA 2002).

Comparisons suggest that the Earth Observation markets commercially under-perform for several reasons. Despite entry of very-high resolution commercial data providers into the market, few Earth Observation activities generate large profits. In an implicit acknowledgement of non-market benefit streams, the European Space Agency notes that budget and employment figures provide helpful comparators but do not provide a complete assessment of space activities. The Agency states that fields such as meteorology, funded through civil space programmes but outside the commercial sector, bring indirect socio-economic benefits to users and society without generating income.

Similar to some environmental goods and services, the market share of Earth Observation does not accurately reflect derived non-market benefits. Millard et al. (1998) state that a new approach for assigning value to information is required to reflect non-marketed services. Incomplete value-appraisals prevent accurate evaluation of data. In Earth Observation, outcomes of a comparison of market performance with more commercial activities support the hypothesis that inclusion of so-far 'missing markets' would give a more realistic picture of costs against true benefits. Themes of non-market value are examined in detail in chapter four, and non-market data usage is revisited in chapter six.

The unique perspective offered by Earth Observation platforms suggest that data may have evidential value in legal proceedings. Synoptic views from space-borne sensors combine with legal frameworks which support unconstrained international surveillance to provide detailed information without breaching national frontiers or air-space. These issues, explored in the military domain, led to the replacement of airborne reconnaissance assets (such as the U-2 spy plane) by spaceborne sensors such as the CORONA programme. Technology transfer from classified to commercial arenas has increased the spatial and spectral precision of remotely-sensed images. This development brings into focus new capabilities and concerns, leading to calls for policy updates to reflect new capabilities which were not foreseen when legislation was ratified (Harris 2003, Rao and Sridhara Murthi 2006).

Satellite remote sensing has not yet been widely used in legal cases, although more widespread use is likely in the future. Many forms of digital data are routinely presented in legal proceedings, including photographs and digital audio recordings. Automatic digital remote sensors such as traffic enforcement cameras provide a detailed and proven policy model which supports the use of satellite images as evidence on condition that the probity and origin of such images can be adequately proven (Staggs 2001, Jäger et al. 2005). Furthermore, digital remote sensing images have been accepted as evidence in support of United Nations Security Council interventions without supporting ground-based intelligence data in Iran, Iraq, Sudan, Afghanistan and Kosovo (Dehqanzada and Florini 2000, HMSO 2003, US Agency for International Development 2005, *The Guardian* 2006). Data was covertly acquired and was processed prior to submission. Figures 3.6 and 3.7 show images of this kind.

Commercial availability of very-high-resolution satellite images within the public domain has brought a shift towards greater transparency in government and industry. In areas such as international treaty compliance, agricultural subsidy and fishery monitoring, required data are not readily available from sources other than Earth Observation. These applications are likely to become more important, as increasingly stringent legislation aims to counter environmental degradation and economic impacts of climate change (Stern 2006). It is expected that damages which result from transgressions of international law, such as oil spillages, will increasingly be paid for by those responsible. Earth Observation allows the identification of perpetrators even when crimes are committed in international territory, far from the nearest traditional law-enforcement bodies.

Chapter 4 PUBLIC GOOD AND EARTH OBSERVATION DATA

4.1. *Introduction*

4.1.1. Aims

The Public Good status of Earth Observation data has not been rigorously examined despite a maturing market and increasing data usage in decision-making (Georgiadou and Groot 2002, Peter et al. 2006). Differing legal frameworks and management strategies precipitated divergent data policies in Europe and the USA, complicated by the application of inconsistent information management regimes (Harris 2002, Von Der Dunk 2002, Georgiadou and Groot 2002). Harmonised data policy requires, and must build upon, a multilaterally agreed definition of Earth Observation data characteristics.

Significant components of Earth Observation data value lie outside markets. These 'non-market' benefit streams are excluded from traditional accounting. In particular, Public Good characteristics are poorly represented in many valuation strategies (Pearce 1993), which weakens the advocating leverage of Earth Observation. Positive non-market externalities that are not captured constitute hidden markets, and their exclusion leads to the undervaluing of Earth Observation, incomplete analysis and insufficient consideration in policy decisions (BEA 1994, Rietbergen-McCracken and Abaza 2000).

To justify the inclusion of data in decision-support or policy formulation, non-market value and Public Good status must be characterised. In addition, it is proposed that an accurate assessment of the position of Earth Observation data as a Good will help to inform policy by providing tools and strategies, already proven in other fields, for the effective valuation of Earth Observation data. This is of particular importance with reference to new programmes such as Global Monitoring of Environment and Security (GMES) in Europe and Global Earth Observation System of Systems (GEOSS) in the USA.

4.1.2. Scope

In economic terms, commodity value represents an intensity of consumer preference. When consumer willingness-to-pay matches or exceeds item price, which serves as an excludability mechanism, a purchase can be made. Fullerton and Stavins (2000) state that perfect private markets provide the "greatest good to the greatest number", as long as they function efficiently.

Theoretical Private Good commodities are rivalrous and exhibit consumption scarcity (Pearce 1993), because use of the Good diminishes its availability to others. The Good must be excludable to ensure that prices and other exclusion mechanisms effectively control the number of beneficiaries. If non-paying users cannot be excluded from benefits then pricing fails due to free-riding. Private Goods trade requires a property rights structure, delineating ownership (Pearce 1996). The Stock Exchange is an example of a relatively pure functional private market - Fullerton and Stavins (2000) assert that "many buyers and sellers operate with low transaction costs and good information to trade well-defined commodities with enforced rights of ownership".

Some commodities cannot be efficiently traded within private markets because they are non-rivalrous or non-excludable. This applies to Common Pool resources, Club Goods and pure Public Goods. A variety of economic provisions and special policy instruments exist for the management of such goods outside private markets. Policies such as taxes and quotas ensure that non-Private Goods are not subject to market inefficiencies which lead to under-provision and excessive free-riding (Pearce 1996). In addition, the reluctance of individuals to reveal intensity of need causes shortage in funding and supply without special provisions (Tietenberg 2003).

When the Public-Private status or 'publicness' of a good is unknown, assumptions underlying market theory can be broken. Elements of non-rivalry and non-excludability cause inefficiency and lead to market failure. Failing markets can be maintained, typically using three approaches.

- In cases where a small market is dominated by a single supplier, antitrust legislation can be invoked
- If economies of scale are such that a single supplier holds a monopoly, then prices can be regulated
- If elements of the commodity are Public Good in nature, it is justifiable to fund their provisions through central government (using special policy mechanisms)

Because market development strategy and data policy enable the framework for implementing special policies for Public Good management, the status of commodities must be established early and with certainty.

This chapter discusses the publicness of Earth Observation data as a commodity – the degree to which the data is non-excludable and non-rivalrous – in order to examine how the Public Good value of Earth Observation data can be captured and included in policy decisions. This information can be used to recommend inter-agency data management approaches which capture all elements of value and allow the deployment of appropriate special policy instruments. Special and unusual qualities of Earth Observation data make these value-assemblies complex and variable. Examples that are assessed in this chapter include Bequest Value, Existence Value, Use / Non-Use Value and Option Value.

4.1.3. Chapter Structure

This chapter is divided into seven sections. It begins with an examination of data policies from Europe and the USA, which reflect differing attitudes to data valuation and support different space agency funding mechanisms. Ito (2000) concludes that data policies are inconsistent and fragmented, both internationally and between Earth Observation systems. Consistent and informed discussion of value is required to form the basis of robust and logical data policy.

If components of satellite data value lie in the Public Good domain then monetisation strategy and data policy should integrate non-market components of social value in order to more completely capture value.

Valuation of Public Good resources is well-developed in the field of environmental economics, so the second section of the chapter refers to the origins of traditional Public Goods and examines valuation problems. The following concepts and types of value are introduced.

- Willingness to Pay (WTP)
- Willingness to Accept Compensation (WTA)
- Use Value
- Option Value
- Passive Use Value (also called Non-Use Value)
- Bequest Value
- Existence Value

The third section characterises interactions between types of value and consumers, and introduces strategies that have been developed to capture non-market value-types. Advocation of total willingness-to-pay (tWTP) in preference to Total Economic Value (TEV) as a scheme of measurement indicates that combinations of passive value-types with traditional Value of Marketed Information (VOMI) approaches most accurately capture the welfare impacts of goods and services. Valuation strategies are briefly discussed.

The fourth section of the chapter introduces an innovative map of publicness, designed to identify types of goods using a feature-space coordinate system using axes of excludability and rivalry. The following types of Goods are included in the map, and are subsequently defined and discussed. For each Good, optimal management approaches are suggested.

- Public Goods
- Common-Pool Goods
- Private Goods
- Club Goods

- Merit Goods
- Orphan Drug Scenario Goods
- Information Goods

The fifth theme of discussion returns to satellite data policies, focusing on pricing and distribution strategies in digital information. The following management regimes and exclusion devices are included.

- Free Access
- Non-Cost Allow Lists
- Coarse and Fine Exclusion
- Marginal and Incremental Pricing
- Tiered Access
- Encryption Systems
- Full Price to All

The sixth section categorises Earth Observation activities according to their Public, Private or Mixed Good characteristics. Building on the innovative approach proposed using feature-space concepts, nine satellite missions are assessed. The map shows that Earth Observation data is very variable in terms of publicness. An assessment of this kind provides an important insight into non-market data value and can inform policy-making and help to design sustainable and appropriate pricing and distribution policies.

The final section introduces temporally variable publicness. The location of a data set within the landscape of publicness is not fixed but changes over time, depending on the currency and value of the data, the age of the sensor and the funding sources that support its operation. Themes of temporal change in Public Good status are revisited in Chapter 6, which assesses the utility of satellite data for humanitarian purposes. The chapter investigates whether non-market applications are 'socially profitable', and how value can be attributed to Earth Observation sources through activities with no market presence.

4.1.4. Background

Digital geospatial data has gained acceptance in many fields including agriculture, forestry, oil and gas, civil engineering and disaster management (Bjorgo 1999, Sutton and Costanza 2002, Häusler 2003, Coccossis 2003). Coincident with the uptake of GIS, governments and major organisations use digital geodata at many stages of their operations. Data acquired from space is used to monitor global environmental change, determine agricultural subsidies (EARSC 2006, MARS PAC 2006), map inaccessible regions and enforce international legislation (APERTURE 2000, Ainsworth et al. 2001, ESA 2002).

Despite Earth Observation involvement in multi-million Euro decisions such as the MARS programme, there has been no assessment of Public-Private data characteristics in such decisions (Georgiadou and Groot 2002), leading to inconsistency in the application of management and market-development strategies. Harris (2002) identifies a need for such clarification, stating that "the main international tensions in Earth Observation are brought about by differing answers to the question of who pays for Earth Observation ... is it a public good or is it an information service with an independent foundation ... ultimately paid for by users?"

Previous research indicates that many benefit streams of Earth Observation data reside outside the market and that global commercial revenue is modest: around £2.9 billion per year (Cookson 2002). Earth Observation competes with other space activities such as communications or navigation for investment-share, but where other recipients of space budgets have defensible revenue streams, the value of Earth Observation is under-represented when non-market components of value are excluded.

In 2002, the global space-borne communications value-adding segment was worth £29.6 billion, yet for the same period Earth Observation value-adding totalled just £0.43 billion (Euroconsult, 2001). Projections for 2010 revenues suggest that continuing exclusion of non-market value leads to a broadening value-gap: whereas communications value-adding may generate as much as £97 billion, Earth Observation revenues are projected to be £3.6 billion (ESA 2002). Lehman Brothers model 2006 revenues and conclude that imaging contributes just 0.84 per cent of annual satellite revenue, while over 60 per cent is derived from satellite television and communications reselling (ESA 2002). Informed by the revolution in environmental accounting that has led to widespread acceptance of the need for valuing natural capital stocks and a re-evaluation of free gifts from nature (Pearce 1993, Costanza et al. 1998, Stern 2006), perhaps it is time for the 'free gifts' of Earth Observation to be considered?

Earth Observation provides decision-support and contributions to understanding which may not be marketable (Quaife 2006, personal communication). Future environmental legislation is likely to demand accurate costing of all externalities, including those outside the current market such as carbon emissions. Backhaus and Beule (2005) confirm that "the fulfilment of observation tasks and reporting obligations" forms a significant driver for public-sector Earth Observation development. Furthermore, unsustainable consumption of environmental goods and services depletes natural capital stocks which are inadequately costed; measures of economic performance based on profit and wealth are not proxies for total welfare change (Daly 1992) and do not represent shifts in the global value of ecosystem goods and services (Costanza et al. 1997). It seems that space-borne sensors can provide key information required for the creation of environmental accounts, which cannot be easily collated in any other way. In this case, if the viewpoint afforded from space is unique, then special value considerations apply relating to the protection and stewardship of irreplaceable information assets.

4.1.5. **Data Policy**

Inadequate definitions of data characteristics have impeded development of the Earth Observation marketplace; Rosenholm and Harris (2002) state that "progress has been extraordinarily slow and industry profitability poor, although [non-market] value for society has been proven in many areas".

Commercial satellite operators continue to struggle in the private sector: "leaning on government support, US remote sensing operators now seem content to court government business almost exclusively, as there is much less emphasis on development of the commercial base" (*EOportal News* 2006).

4.1.5.1. ***USA***

In the United States, data policy developed in adherence to founding principles governing NASA and NOAA as part of the Federal government – those of centrally-funded agencies with joint objectives of scientific endeavour and the management of public-interest projects (Harris 2002). Policies advocating free exchange of data and unrestricted access are appropriate for publicly-funded entities to avoid double-taxation. Tax revenue is used as a special policy instrument to fund NASA, NOAA and the national military force – examples of Public Good resources in their own right. Should citizens enjoy unrestricted use of the data they have paid for through taxation? Controversy followed commercialisation of the Landsat programme in the mid 1980s (discussed in section 3.2.2.4). Stallkamp (2006) comments that "the government were subsidising the commercial effort with a US $250 million transition commitment, while at the same time being one of the primary purchasers of the data, now at a much higher [market] rate". Stallkamp goes on to emphasise that market development fell short of expectation, and that many objected to commercialisation on the basis that they were "paying again for data that had already been paid for once with tax dollars" (Stallkamp 2006).

Global use of this data is, from an American perspective, simultaneously a positive non-market externality and an acceptable degree of free-riding[1]. A USGS Landsat 7 Program Manager justifies free access in an interview, stating: "I hope and believe that the Landsat data policy ... will spawn new

[1] This positive non-market effect is evident in the Humanitarian Aid sector. Free Landsat data dominate usage statistics, due to their low cost and unrestrictive licence. 24 per cent of all sensor citations referred to the Landsat platform in a survey of Aid professionals (Chapter six).

applications and innovation throughout the remote sensing business, including research ... proliferation of operational applications throughout the business and growth of the value-added industry" (Thompson 2000). Alongside such proponents, cynical observers note that the USA receives strategic and political advantages by occupying a lead role in surveillance and space activities. Even under "free and unrestricted" American data policies, no transfer of ownership occurs – although a licence is granted to allow unrestricted data use, the data itself remains US Government property.

4.1.5.2. ***Europe***

European legislation supporting the European Space Agency (ESA) determines that the agency has a responsibility to support "scientific research [and] the world competitiveness of European industry" through member-state contributions, but without direct funding through public taxation (ESA 1975, in Harris 2002). ESA facilitates research and development of new technologies with a focus on stimulating the private-sector adoption of information products. It is clear that development of sustainable markets for Earth Observation data has been an objective of ESA since the formulation of the original ERS data policy, in contrast to the US strategy. Peter et al. (2006) state that "space-based applications are primarily technology-driven, and the requirements from end-users are rarely taken into consideration" – an American viewpoint reinforced by Stallkamp (2006), who comments that until recently "most remote sensing satellites were experimental, with emphasis placed on developing the technology rather than using the data". This aim is not reflected in the Envisat data policy, which identifies a category of use specifically aimed at operational and commercial use (Category 2, ESA 1998) with the aim of supporting market development.

4.1.5.3. ***Conclusions***

Harris (2002) notes that unless ongoing funding is secure, as in the USA, agencies will use data pricing as a mechanism in the "search for other sources of funds". Yet the funding status of organisations cannot alter the Public Good characteristics of the data they provide, because elements of value cannot be conferred or superimposed upon data using policy measures alone (Georgiadou and Groot 2002). Data policy studies have concentrated on the Public Good status and management of agencies themselves, illustrated by Harris (2002) who states that "the centre of the pricing policy question is the funding basis and the intentions of the supplier organisation". Indeed it may be the case that NASA and NOAA function as Public Goods agencies, but ESA does not. This is somewhat beside the point, as publicness of value is not decided by organisational structure but can be embedded within data. NASA and ESA are supported by different mechanisms and have different objectives but the categories of data created and distributed are the same. This chapter examines the status of data to discover components of its value, and recommends this analysis to inform policy. To date, this process has been neglected - Ito (2005) concludes that "data regulations, including the data policies of different Earth Observation system are fragmented and non-uniform at the moment".

4.2. Public Goods

4.2.1. Definition

Definitions of Public Good resources including elements of non-rivalry and non-excludability were formalised in seminal papers by Samuelson in 1954 and 1958, which state that the consumption of non-rivalrous goods cannot limit availability to other consumers. Non-rivalrous resources cannot exhibit consumption scarcity (Samuelson 1958, Pearce 1993). To be considered non-excludable, all consumers must be free to derive benefit from a Good; in practice it must be impossible to regulate access.

In simple terms, clean air is both non-rivalrous and non-excludable[2]. Once the air has been cleaned it is impossible for an individual to use so much that another individual is prevented from deriving benefit (Tietenberg 2003). It is also very difficult to prevent individuals from making use of the cleaned air once it has been released. Pearce (1996) considers positive and negative

[2] We do not consider who initially polluted the air, who paid to clean it and whether it is released into an enclosed, private space – these issues considerably complicate the matter.

externalities arising from Public Goods, defining them in terms of "global Public Goods and Public Bads." The negative consequences of stratospheric ozone depletion constitute a "global bad", in that no-one is excluded from the negative impact, and its magnitude is not diminished by the number of affected individuals.

4.2.2. **Monetising Public Good**

Measuring value of non-market commodities poses challenges because they influence welfare without passing through markets; as Tietenberg (2003) comments "it is not possible to check your local grocery store for the price of clean air." Measures of consumer intensity of preference are used in lieu of prices, but matters are complicated because consumers typically conceal their need for Public Goods as part of the Free-Rider phenomenon (Pearce 1993, 2000). Investigating this problem it is important to relate non-market value to economic terms, as Pearce (1993) notes: "the world's economies have not fared very well under environmental policies which are almost entirely dominated by non-economic considerations of worth and value". Schleicher-Tappeser (2000) discusses market failures identified by Pearce, and affirms that "development is only measured in economic terms; social, environmental and cultural aspects [of value] are not included".

In the UK, the British National Space Centre clarifies procedure and comments that "in government, although talk of non-financial aspects of value is academically interesting, for purposes of policy-making and debate it is quite clear that pounds-and-pence values are ultimately required" (Grimmett 2005). This may be problematic, and Pearce (2000) outlines a common misunderstanding in monetising non-market goods. It is not possible to attribute values directly to the Good, but approaches discussed here ascribe financial value to individual *preferences*, thereby "using money as a measuring rod". Kerry Smith (1996) refers to a process of revealing missing components of choice.

> By reconstructing the elements of a [consumer] choice, non-market valuation methods demonstrate that a monetary measure of economic

> value can be developed from an individual's decisions in a wide range of circumstances. This process requires ingenuity because there is often a need to supplement what is observed (Kerry Smith 1996).

According to Costanza et. al (1997), "there have been many studies in the last few decades aimed at establishing the value of a wide variety of [non-market] ecosystem services" but no one-size-fits-all approach has gained currency in the face of increasingly rigorous environmental legislation. In fact, a wide variety of economic measures of value can be applied to Public Good resources to ensure that they can be:

- Adequately weighted alongside market activities in investment policy decisions
- Compared with other approaches in a meaningful and insightful way
- Used to evaluate the non-market effects of legislative change
- Used to capture and represent human wellbeing and individual preference

Failure to financially quantify non-market components of value leads to systematic under-provision of Public Goods and services. The merits of activities with non-market value are currently under-represented; "missing markets" mean that funding decisions are formed with partial information. In addition, baseline and ongoing measures of non-market phenomena may be required to monitor and evaluate legislative change and policy (Nordhaus and Kokkelenberg 1999). For goods with some element of Public Good, the absence of market prices "does not mean ... that they do not have value, or that the value cannot be translated into money terms and compared with other things that are valued" (Markandya and Richardson 1992). Bingham et al. (1995) review approaches for valuing environmental Public Goods and conclude that "semantic difficulties in current valuation terminology are a barrier to progress in developing improved ecosystem valuation methods." In this light, terms used to attribute financial measures to non-market effects are clarified.

4.2.3. Core Values

4.2.3.1. *Willingness To Pay or Accept Compensation*

Where no market price exists, the key to evaluating value is willingness-to-pay (WTP), expressed as the amount an individual would pay to secure a commodity[3]. Willingness to accept compensation (WTA) measures the inverse; what payment would an individual require to atone for the loss of a service or amenity? According to Pearce (2000), historical economic theory suggested that willingness-to-pay and willingness-to-accept-compensation were almost equivalent, "within about five per cent ... [because] both are essentially measuring the same thing". Some research suggests that is not always the case, and Markandya and Richardson (1992) refer to empirical studies in Psychology, which suggest that "individual aversion to a loss is stronger than attraction to an equivalent gain".

In fact willingness-to-accept-compensation often exceeds willingness-to-pay by factors of 4-15 times, which raises questions about which should be used. Pearce (2000) suggests that willingness-to-pay and willingness-to-accept-compensation commonly diverge in situations where no substitute for the Good exists. Due to escalating Option, Existence and Bequest Values, which are discussed shortly, unique resources demand higher WTA values. Willingness-to-accept-compensation is also more relevant when individuals are being asked to forgo a Good to which they have access rights (clean air, for example). Total willingness-to-pay (tWTP) must be deconstructed to discuss elements of value and their influences.

$$tWTP = Use\ Value + Option\ Value + Passive\ Use\ Value$$

4.2.3.2. *Use Value*

Welfare benefits provided by a commodity to individuals both now and in the future constitute Use Value. Markandya and Richardson (1992) note that

[3] Note that willingness-to-pay still exists in markets; if price is lower than willingness-to-pay then a purchase will be made. If willingness-to-pay is lower than price then the individual will 'vote no' and decline the transaction (Pearce 1993).

"[the word] 'use' in this context does not imply physical contact", so a reader of books about the Amazon Basin would derive Use Value from the area. To use more relevant examples, viewers of television weather reports are entitled to express Use Value for the sensors used to acquire satellite meteorological data. Use Value in this context, even for Public Good commodities, is based in the "behavioural trace in the markets" left by viewers (Pearce 2000). To extend the weather example, the data materially contributes to the success of a derivative media distribution market, despite the fact that "meteorology doesn't have commercial value" (Euroconsult 2002).

4.2.3.3. ***Option Value***

Uncertainties in the future exploitation of goods are reflected in Option Value (OV). If consumers may or may not make use of a resource, a willingness-to-pay is captured to reflect the value of maintaining the element of choice through commodity preservation.

Markandya and Richardson (1992) cite a playground as an Option Value resource; the consumer played in the area as a child but is now too old to make use of facilities. The individual expresses or reveals willingness-to-pay to avert redevelopment on the grounds that his or her children may one day choose to use the equipment. Elements of uncertainty are introduced by changing circumstances and human choice: perhaps a better playground will be built nearby or the individual will move out of the area. Although future-benefits have been paid for (protecting the playground), it is not clear whether they will be fully realised.

The essence of Option Value lies in the willingness to pay *now* to protect the *possibility* of deriving benefit in the future. Krutilla (1967) comments that future-benefits are not always realised. Furthermore, some individuals never wish to exercise their right to use resources: Option Value expresses sentimental attachment, to the extent that "an option demand may exist therefore not only among persons currently and prospectively active in the market for the object of the demand, but among others who place a value on the mere existence [of the object]." This complication infers overlap between Option Value and Existence Value.

Analysing wider applications of Option Value, Plummer and Hartman (1987) state that Option Values can be significant inputs to tWTP, especially for Public Good resources with little certainty of supply. They refer to the empirical work of Fisher and Raucher (1984), which indicates that the Option Value of clean water is at least 50 per cent of the direct Use Value. Option Value can affect a much greater population than the water user-group so its influence is large. Krutilla (1967) examines Option Value with reference to irreplaceable, rare or unique resources for which there is no viable substitute (and which may already be threatened). In association with very large willingness-to-accept-compensation costs associated with limited choice-experience (Coursey et al. 1987), the Option Value of such resources may also be very high. Brookshire et al. (1983) introduce the caveat that Option Value functions as a "risk aversion premium." Risk-taking individuals, or a guaranteed ongoing supply of the commodity can lead to negative Option Value.

4.2.3.4. ***Passive Use Value***

Individuals allocate Passive, or Non-Use Value (NUV) to resources they will never experience even indirectly. The application and inclusion of Non-Use Value is extremely controversial – most definitions include elements of Bequest Value and Existence Value (Krutilla 1967, Coursey et al. 1987, Pearce 1996). Some incorporate Option Value (Kerry Smith 1987) and others introduce Altruistic Value (OECD 2006). In common with findings of Bingham et al. (1995), Kerry Smith (1987) concludes that "consistent definitions for non-use benefits have been elusive because the conceptual frameworks used in the literature ... are not mutually consistent".

Pearce (2000) clarifies that the term Existence Value, coined by Krutilla in 1967, includes all elements of non-use. It is closely related to Option Value because options that are never exercised may be retrospectively categorised as Non-Use Value due to the absence of behavioural trace[4]. Classification of use and non-use is sometimes unclear: Pearce (2000) suggests that "it has something to do with whether or not we can identify changes in behaviour associated with the utility derived from the thing being valued".

4.2.4. **Other Values**

4.2.4.1. ***Bequest Value***

Bequest Value quantifies individuals desire to leave intact non-renewable resources for subsequent generations, encompassing objectives for responsible stewardship of such resources. Bequest Value is particularly high for irreplaceable or unique resources such as the Grand Canyon, Blue Whales or the Norfolk Broads because individuals acknowledge that no level of willingness-to-accept-compensation would allow restoration of the lost asset. In this sense information is often allocated high Bequest Value because even if one returns to the place of acquisition, temporal locations can never be revisited. By protecting resources for future users, the current generation derive welfare which is vocalised as a sense of worthiness in an "exclusively sentimental" domain (Krutilla 1967). When extended to form the concept of impure-altruism (labelled the "warm glow" by Pearce 2000, pg.59), emotional decisions can lead to bias; how can welfare economists separate individuals who are willing to pay to feel good from those evaluating the Good itself? Although sometimes regarded as a component of Existence Value due to empirical difficulties in separating the two (Pearce 1993), it is appropriate in this case to discuss Bequest Value independently due to its special significance in the assessment of informational products.

4.2.4.2. ***Existence Value***

Markandya and Richardson (1992) assert that existence value cannot be easily incorporated into pragmatic or utilitarian schemes of valuation – can "welfare be derived from the very existence of a commodity?" Natural goods

[4] Conversely, OECD (pg. 86, 2006) analyse Option Value and conclude that if the Good is ever consumed, all activity leading back to the original preservation-of-choice decision constitutes Use Value.

and services, according to some economists, have intrinsic Existence Value that predates and precludes any form of anthropogenic valuation – an extreme approach limited in its realistic application. More usefully, Pearce (1993) draws attention to the revelation of willingness-to-pay and Existence Value provided by wildlife and nature charities. Very few contributors actually interact with Giant Pandas, Orang-Utans or the Antarctic and it has been proposed that vicarious consumption of these resources is possible through television programmes and so on, but this argument is weak and misses the point: vicarious consumption is categorised as Use Value due to behavioural trace (interested viewers stimulate a market for nature programmes through their viewing preferences). Hanemann (1994) explains: "only a few people may want to own a Sea Otter pelt, but many may want this animal protected in the wild ... in the presence of [non-market] externalities, market transactions do not fully capture preferences. Collective choice is the more relevant paradigm." Many authors agree that Existence Value most commonly applies where there is no "actual, planned or possible use" by the valuing individual "or for anyone else" (OECD 2006). The themes of Existence Value are similar to Bequest Value, including responsible stewardship and a sense of human responsibility, with one crucial difference. When following generations are expected to make use of a resource, Bequest Value is used yet when they can benefit from it without allocating Use Value, then Existence Value may be more appropriate (OECD 2006), shown Figure 4.1.

4.2.5. **Interactions**

Characterising value-types is challenging but essential for the derivation of meaningful estimates of tWTP. Where no market prices exist the assessment of willingness-to-pay provides a model of demand with two primary uses: facilitating fair competition with commercially-driven alternatives, and the efficient management of the Good in the absence of market forces. Pearce (2000) refers to these monetisation activities as "proper pricing". In the past, tWTP has been used interchangeably with Total Economic Value (TEV), which is defined as the sum of direct and indirect Use Value added to Existence Value (Pearce 1993, Adger et al. 1994).

Specifically, OECD (2006) state that TEV does not "provide an all-encompassing measure of the economic value of any environmental asset." It is a simplistic approach which neglects the central anthropocentricity of revealed preferences, Bequest Values and missing markets; Pearce (1996) asserts that "valuation is of preferences held by people" *not* the non-market Good itself, and Freeman (2003, cited by OECD 2006) notes that tWTP includes Option Value but TEV cannot. Divisions between types of value are dynamic, complex and sometimes unclear (Bingham el al. 1995, Pearce 2000, OECD 2006). Value types that contribute to tWTP are illustrated, Figure 4.1.

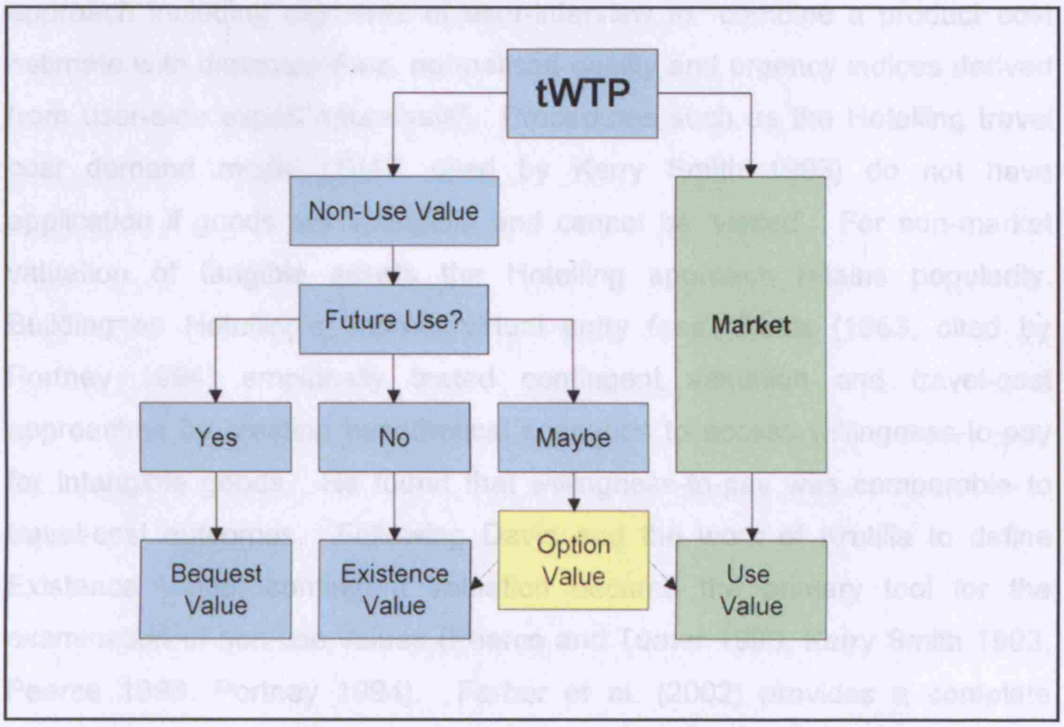

Figure 4.1 Total willingness-to-pay (tWTP) and its component value types (adapted from OECD 2006)

Marketed value-adding activities are accurately captured using established accounting techniques (Euroconsult 2001, ESA 2002, 2004), but do not reflect the relative welfare-impacts of Earth Observation data, which include significant non-market benefits and positive externalities. Referring to Figure 4.1, most Use Value can be quantified and expressed as Value of Marketed

Information (VOMI). Special approaches are required to assess total Non-Use Value and enable the proportional representation of Bequest, Existence and Option values (Backhaus and Beule 2005, Pearce 1993, Rietbergen-McCracken and Abaza 2000).

4.2.6. **Valuation Techniques and Problems of Non-Use Value**

Approaches originally developed for environmental accounting offer most potential for capturing non-market values. Within these, Pearce (1993) concludes that "only experimental market approaches [which include contingent valuation, contingent ranking and stated preference methods] can capture non-use values". Backhaus and Beule (2005) recommend a hybrid approach including elements of user-interview to "combine a product cost estimate with dimensionless, normalised quality and urgency indices derived from user-side expert appraisals". Procedures such as the Hotelling travel cost demand model (1947, cited by Kerry Smith 1993) do not have application if goods are intangible and cannot be 'visited'. For non-market valuation of tangible assets the Hotelling approach retains popularity. Building on Hotelling's implicit 'virtual entry fees', Davis (1963, cited by Portney 1994) empirically tested contingent valuation and travel-cost approaches by creating hypothetical scenarios to access willingness-to-pay for intangible goods. He found that willingness-to-pay was comparable to travel-cost outcomes. Following Davis and the work of Krutilla to define Existence Value, contingent valuation became the primary tool for the examination of non-use values (Pearce and Turner 1990, Kerry Smith 1993, Pearce 1993, Portney 1994). Farber et al. (2002) provides a complete review of valuation techniques for natural resources.

4.2.6.1. ***Contingent Valuation***

When commodities do not have viable substitutes and implicit trading cannot be used to derive prices, valuation methods which are reliant on revealed preference cannot be applied (Brookshire et al. 1982, OECD 2006). If hypothetical market scenarios are proposed it is possible to derive willingness-to-pay by using participant choices to "elicit personal valuations" (Rietbergen-McCracken and Abaza, 2000). Careful survey design and the use of "bidding games" (which can be used to reduce bias by obscuring the true purpose of questioning from participants) allow a form of direct questioning known as contingent valuation. Considerations for designing contingent valuation implementations to avoid bias are summarised by Hoehn (1987) and Hanemann (1994), who note that guidelines for obtaining valid responses are stringent and inflexible because "simplistic dichotomies" do not yield representative results.

Markandya and Richardson (1992) and Pearce (1993) assess potential problems with contingent valuation, noting that willingness-to-pay values may be largely invalid when participants are unfamiliar with the Good in question. When there is no market for Goods, inexperienced bidders initially over-state willingness-to-accept-compensation before re-evaluating as experience is gained. This convergence of willingness-to-pay and willingness-to-accept-compensation over repeated experiments has been attributed to participant "wishful thinking" in terms of influencing the supply of a Good. This is also known as Information Bias (Hoehn 1987, Coursey et al. 1987). Strategic Bias or "gamesmanship" is also a problem, because users aim to reduce their potential fee burden by understating willingness-to-pay (Brookshire et al. 1982). If participants think that Goods will be provided even if they state low willingness-to-pay, free-riding issues can also be introduced, as identified by Pearce (1993).

Bishop and Heberlein (1979) assess the capabilities and biases of contingent valuation. They state that "recreation [and other non-market] economics has a long way to go before it can claim accuracy comparable to analyses of market phenomena". Recommending further research, they maintain that "research is essential if economists are to help recognise the contribution of extra-market goods to the overall level of economic well-being and facilitate sound assessments of the trade-offs between market and extra-market goods and services". Pearce (1993) states that Non-Use Value is highest for assets that have few substitutes; "in such circumstances it is *very important* that non-use values be investigated". When components of value reside outside markets and large Non-Use Value values are expected (there are few substitutes), then contingent valuation-based measures of value represent a means of accessing applicable measures of willingness-to-pay that is well-proven.

Further to work by Bishop and Heberlein (1979) and Brookshire et al. (1982), the scope of contingent valuation was tested in an environmental context in 1992, when NOAA assessed approaches for evaluating environmental damages. The assessment followed a Federal Court of Appeal ruling that lost existence value should be treated equally alongside other economic costs. Portney (1994) raises the question should NOAA consider "lost existence values as fully compensable damages and identify the contingent valuation method as the most appropriate way to measure them"? Or were the concerns of petrochemical companies regarding the applicability and rigour of contingent valuation well-founded?

In the course of eight meetings the 1992 NOAA assessment panel considered over twenty expert testimonies and concluded that "contingent valuation studies can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive-use values" (NOAA, cited by Portney 1994), subject to certain procedural conditions, summarised by Hanemann (1994). Since the panel report was made available contingent valuation has gained currency.

4.2.6.2. ***Accounting for Public Goods***

The need for Public Good accounting was recognised when environmental accountants drew attention to the exhaustible nature of natural assets and their unsustainable exploitation in the pursuit of economic growth (Markandya and Richardson 1992). Some suggested that the Earth's natural capital stock system analogously complied with the laws of thermodynamics and there was a finite capacity for waste absorption (Farber et al. 2002), in the form of unmanaged negative externalities. Costanza et al. (1997) stated that consumption of natural resources without recompense "may ultimately compromise the sustainability of humans in the biosphere". Environmental accounting aims to address the withdrawal of natural capital investment represented by resources extracted from the ground or harvests of living species – commodities previously regarded as "free gifts of nature" (BEA 1994). Environmental accountants argue that payment should be made for the consumption of these goods, consonant with their cost of creation; asymmetrical accounting[5] cannot provide tools for effective resource management.

Markandya and Richardson (1992) blame reduced unemployment, increasing wealth and the greater availability of goods after the Second World War for a shift in consumer demand towards commodities that could not be provided by the private sector. Industrialisation, population growth and rapid urbanisation led to clean air and water scarcity. In 1969, American consumers were shocked by press reports of indiscriminate pesticide use. Responding to public pressure, the US Environmental Protection Agency (EPA) was founded the following year, with a mandate to protect Public Good resources that fell outside the market. EPA initially worked to assess the effects and costs of negative environmental externalities such as polluted rivers (Markandya and Richardson 1992). It became clear that traditional approaches did not capture externalities, so economists assessed the costs of environmental protection (King 1966, Hueting 1970) and discussed "missing markets" (de Groot et al. 2002).

In 1975, the foundation of the US-based Association of Environmental and Resource Economists stimulated a step-change in research (Masood and Garwin 1998). Neoclassical economist's belief that "technology, regulation and market mechanisms will be sufficient to solve environmental problems such as energy and food shortages" was not shared by environmental economists, who assert that simple taxation schemes to provide for

[5] Accounting for the addition or depletion of stock requires symmetry in supply (capital formation) and consumption accounts. Asymmetrical accounting permits the omission of one entry, as in the case of some minerals (BEA 1994). This has been shown to allow unchecked over-exploitation and restrict the scope of productivity monitoring (Nordhaus and Kokkelenberg 1999).

mitigation costs were ineffective instruments of control: the effects of negative externalities could be regional or global (Costanza et al. 1997, Pearce 1993, 1996). Increasing environmental research (including the discovery of stratospheric ozone depletion and anthropogenic climate change) was facilitated by scientific advances. New environmental data informed the development of new and complex strategies for externality-management, to reflect "trade-offs between society and the rest of nature" (Farber et al. 2002). Tools include international treaties, permits and emissions trading and Global Environmental Markets theory (Pearce 1996, Tietenberg 1994, Stavins 2000). In capturing externalities of global Public Goods and Bads (Pearce 2000), Villa et al. (2002) identify poor data availability as the key factor limiting widespread implementation of ecosystem goods and services valuation, and state that requisite sources are "scattered, incomplete and difficult to use", a conclusion shared by Costanza et al. (1997).

4.2.7. Categories of Goods

Much environmental economics debate centres on categorisation of "publicness of Goods" (Masood and Garwin 1998, Georgiadou and Groot 2002) through assessment of rivalry in consumption and excludability and the extent to which Non-Use Value should be included in analyses. Kerry Smith (1993) highlights the need for "a methodology for valuing and quantifying non-marketed ... resources" and suggests that such a technique could assist in the application of appropriate policies and management, optimised depending on the characteristics of the Good. Clarification of public-private status is needed for effective management because Good's niches can be managed using a wide variety of approaches and policy instruments. Categorising Goods allows legitimate and informed discussions of value leading to the implementation of consistent and appropriate management tools. Following categorisation, all stakeholders should adhere to the same Public Good definition to avoid confusion over data policies, dissemination and strategy (Ito 2005), which "often are complicated, riddled with contradictions and inconsistent across government agencies, even within single states" (Longhorn and Blakemore 2003).

Setting aside issues of property rights (Pearce 2000), public-private Good status can be represented as a landscape, shown in Figure 4.2. The map is populated with zones, as show in Table 4.1. Pearce (2000) notes that "pure" goods rarely occur in reality; the categories of Figure 4.2 are only delineated by boundaries for illustrative purposes. The space forms a continuum through which commodities and assets can migrate over time as property rights, excludability and rivalry (which when taken together define publicness) change (Buchanan 1965, Georgiadou and Groot 2002). Following Figure 4.2, characteristics of Goods are discussed.

Table 4.1 Types of Goods and their characteristics

Zone	Type of Good	Characteristics
1	Public Good	Simultaneously non-excludable and non-rivalrous (e.g. national military defence, public street lighting)
2	Common Pool Good	Non-excludable but rivalrous: consumers compete for finite stocks (e.g. international sea fish, seats on a public bus)
3	Private Good	Rivalrous and excludible in consumption (e.g. food in a supermarket, clothing, goods in a market-place)
4	Club Good	Non-rivalrous in consumption, but mechanisms exist to exclude consumers (e.g. bridges, broadcast television)
5	Merit Good	Consumption encouraged for societal benefit, provision through private sector is possible (e.g. education)
6	Orphan-Drug Scenario	Market economics leads to under-provision and human suffering (e.g. minority drugs, developmental assistance)
7	Information Good	Non-rivalrous, but excludability is variable and depends on costly instruments (e.g. software, intangible data)

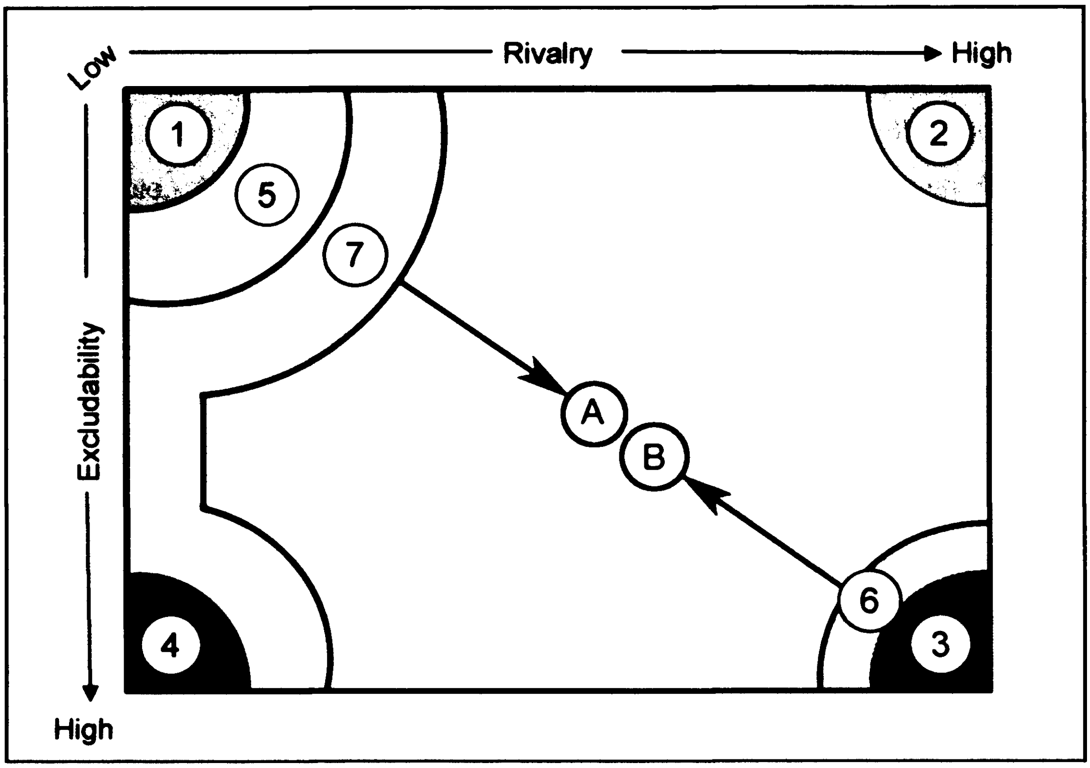

Figure 4.2 The landscape of Goods mapped as a feature space of Excludability and Rivalry. Numbers on this map correspond to value types in Table 4.1.

In addition to broad Public and Private categories of Goods shown in Table 4.1 and mapped to Zones 1-4 on Figure 4.2, impure combinations of rivalry and excludability are found in Zones 5-7. They represent Merit Goods, Orphan Drug Scenario Goods and Information Goods. In addition, vectors A and B describe movement between states within the feature space of 'publicness', motivated by provider and consumer activities. Resource types, and the relationships between Goods are now examined in more detail.

*4.2.7.1. **Common Pool Resources***

When goods are rivalrous and non-excludable, as in zone 2, they reside in the commons, accessible to and managed by everyone (Pearce 1996). Individuals cannot exert property rights and users collectively own and manage the resource as stakeholders. Because individuals may depend on Goods for welfare, the responsibilities and benefits of effective stewardship are shared. Pearce (1996) states that "while common property does have some in-built risks of over-exploitation, it often is a perfectly viable and sustainable form of resource management". Over-exploitation can be regulated and prevented if user communities agree that the good is exhaustible. When common property is administered under Open Access protocols, individualistic game theory leads to resource overuse and eventual destruction (Hardin 1966, Stevenson 1991, Pearce 1996). If individuals consider only their won returns with no concern for the management of the Good, over-exploitation occurs through the "tragedy of the commons", also known as the Prisoner's Dilemma (Hardin 1966). Sustainable use is only possible when consumers cooperate – without collaboration, all are worse off. An example of a Common Pool Resource is fish populations in International waters; they are rivalrous but non-excludable. It is necessary to protect the fish and enforce sustainable fishing using international agreements and quotas. This legislation became possible only when governments acknowledged that fish were endangered through over-fishing.

4.2.7.2. ***Club Goods***

Goods that are consumed in a non-rivalrous manner but from which consumers can be excluded are known as Club Goods (zone 4). Buchanan (1965) refers to a process of extending ownership-consumption rights to differing groups of people so that only accredited consumers are permitted access to the Good. When excluding devices are applied to collective goods in this way, Helsley and Strange (1991) warn that "providers must incur the costs of writing and executing contracts governing the exchange of rights to consume".

Buchanan proposed that a theory of Clubs could "move one step closer to closing the awesome Samuelson gap between the purely private and the purely public good" in support of a continuum of publicness (Figure 4.2) where "few qualify as purely private or purely public" (Georgiadou and Groot 2002). Categorising goods, Buchanan (1965) asserts that few can be non-rivalrously enjoyed by groups of infinite size – the original Samuelson condition for pure publicness – yet many goods share *elements* of publicness in their consumption. When it is possible to determine the "membership margin" or optimal group size, it is favourable to administer the good using a club model.

Several issues omitted in the early club analyses of Buchanan (1965) and Berglas (1976) are of burgeoning importance in Earth Observation and more broadly in the field of digital environmental information. The costs of implementing and administering exclusion devices were not addressed until 1991. Similarly, issues of excludability and quasi-public digital data arose as late as 1994 (Helsley and Strange 1991, Love 1994).

A municipal swimming pool can illustrate management issues in Club Goods. Although the swimming pool is not-for-profit it would be closed if running costs were excessive. It may be financially impracticable for a single swimmer to fund the construction of a pool, so the facility is provided only on condition that users join the club. A fee structure offsets creation and running cost, and users accept conditions of use (most clubs have rules): "any enjoyment of the facility requires the organisation of some co-operative-collective sharing agreement" asserts Buchanan (1965). Users are vetted by the joining process. Typically they must provide personal details and payment. Members are reassured by knowledge that others are qualified to join the club, just as they are.

As membership numbers grow, the per-swim or membership fee (Helsley and Strange 1991) decreases as unchanged costs are borne by more users. This implies that swimmers get better value if the pool has more members. But crowding means growth is not infinitely sustainable under Buchanan's conditions[6]. For Pearce (1996), conversion to Club management is a strategy for reducing rivalry as well as controlling Public Good exploitation. For a vantage point overlooking a fine vista (a Good largely Public in nature), an overload of tourists results in rivalry for an unrestricted view, which can be countered by introducing excludability by charging an entrance fee. Pearce

[6] If the club regulates and controls access to infinitely duplicable digital data, the Buchanan paradigm does not apply in the same way regarding crowding.

states that "in this way, many potentially public goods cease to be public goods because of over-use. In turn, over-use may stimulate controls on access."

Returning to the example of the swimming pool, optimal club size is the result of two constraints. New members are less likely to join a club that already appears congested. Furthermore, existing members may leave to seek less crowded clubs as membership numbers grow. Both scenarios assume that substitutes exist in the form of other local clubs. The efficiency of club management therefore depends on four factors:

- Rivalry between consumers
- Cost of exclusion
- Economies of scale in Goods provision
- The existence of substitute providers / clubs

Buchanan (1965) does not address non-rivalrous impure Goods such as digital data but discusses consumption of pure Public Goods, which are by definition non-rivalrous. If congestion cannot occur then "optimal club size, regardless of goods quantity, is infinite", and club-size equilibrium cannot be met for as long as cost-of-exclusion is assumed to be zero (Buchanan 1965, Berglas 1976). This assumption proves false in the majority of cases (Love 1994), and as Helsley and Strange (1991) state, providers cannot "completely and costlessly exclude consumers from shared resources." Effective management, or club efficiency, is influenced by the cost of excluding mechanisms and by characteristics of the Good.

Helsley and Strange (1991) define costly exclusion using two approaches, termed coarse and fine exclusion. Coarse exclusion is reliant on membership fee to secure club entry. Once the fee is paid, consumers have unrestricted access to the good. Fine exclusion involves membership fees but members must also pay a per-use price. Although the administration costs of fine exclusion are higher, incorporating monitoring and policing expenses, providers retain control over consumption of goods. Within fine exclusion Helsley and Strange (1991) note that "costs will be relatively small for a local swimming pool, since intensity of use is nearly one-dimensional (only the duration of the visit is relevant) and use occurs at only one location". Note that for a multidimensional Good such as distributed and licenced digital information (Love 1994) associated ongoing costs are much higher. Club Goods can be efficiently managed using only coarse exclusion regimes when data is multi-dimensional because fine exclusion would be prohibitively costly.

Buchanan and others assumed that total overhead was equally shared between consumers until crowding occurred. As more users benefit from a fixed-cost resource each must contribute less, so an economy of scale develops. This economy is more pronounced when provision cost for the first user is very high due to fixed costs associated with installation or acquisition[7]: subsequent marginal cost of consumption approaches zero. Love (1994) reviews US government information services, and calculates that serving twice as many users typically incurs increase of less than 2 per cent of total operating cost. In this instance, multiple clubs can access the same Good (Love 1994, Harris 2002). Tiered access and price discrimination allows the classification of users according to willingness-to-pay and publicness of influence. Users without commercial intent whose activities reside in Public Good, Merit Good or selected Information Good domains qualify for a coarse exclusion club, granting unrestricted access at low (marginal) cost. Value-adding users who invest intellectual capital to translate Club Good assets into Private Goods, illustrated by Figure 4.2, vector A, are subject to more expensive metered access, possibly regulated using fine exclusion to prevent misuse. Love (1994) and Harris (2002) review information pricing and dissemination in more detail.

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[7] Love (1994) comments that in many situations the first user responsible for this high cost is government. This is particularly true for Earth Observation. Mitchell (2000) notes that, for a satellite platform, up to US $497 million must be invested before any data becomes available. Private individuals are commonly only subject to incremental costs, which are discussed later in this chapter.

Faced with unacceptable crowding or entry fees that exceed willingness-to-pay, users join alternative clubs. Competition and rivalry can exist in a secondary inter-club marketplace, even when the primary concern is distributing property rights for a non-market resource. Competition to attract members relies on the existence of substitutes, but this is not always the case (Helsley and Strange 1991). Club monopoly is likely when installation of the Good is prohibitively expensive and forms a barrier to entry for competitors, when crowding never occurs and when marginal cost of provision is low (common to intangible Goods).

If competitor barriers to entry are sufficient, or when Good provision is achievable by only one entity (central government, for example) regulated monopoly can be used to monitor supply. Smith (2006) notes that in the case of monopoly control, profit-making can be employed to ensure efficiency and reduce the risk of 'engineered scarcity' as a market demand manipulator. Although profit-making should not be excluded from monopoly regulation, the ethics of exclusion demand that the Merit, Information and Orphan Drug status of the distributed Good are closely examined, and that where appropriate costless club entry schemes are used. When the provided Good is unique, irreplaceable or has no analogue, Existence, Bequest, Option and Non-Use values must be assessed. For non-market Goods they may significantly influence choices of management regime by altering the willingness-to-pay of potential consumers as well as the public at large (Krutilla 1967, Pearce 2000).

4.2.7.3. ***Merit Goods***

Merit Goods (illustrated Figure 4.2, zone 5) could theoretically be provided through the private sector. Consumption is encouraged and facilitated by government due to positive non-market "value judgements" (Stallkamp 2006). Education, an exemplary Merit Good, is provided centrally because it benefits society for all to be well-educated (Love 1994, Stallkamp 2006). If individuals are exposed to market prices and left to choose, Merit Goods are under-consumed because benefits to society are not 'internalised' by consumers. They are under-represented in willingness-to-pay because few consumers are willing to personally pay extra for the 'greater good'. Note that some authors include Merit Goods within Public Good resources. Special policy instruments are required for the funding of Merit Goods to limit free-riding; provision by government cannot be sustainable if it is exploited by non-paying consumers. In the case of education and health, taxes are used to cover costs – although the option of paying more for a different service level still exists in the UK. Love (1994) reflects that "if society values an informed electorate and broad public involvement in public policy debates, then it has an interest in supporting the ready access to a wide variety of government information products and services", through mechanisms of merit good supply.

4.2.7.4. ***Orphan Drug Scenario***

The term Orphan Drug Scenario (zone 6) originates in medical research (Hayes 2001, Seget 2006), but provides useful contributions to other fields. The term was first used in the early 1980s to reflect the growing need for drugs to treat minority conditions. Ratified in US law in 1983 as the Orphan Drug Act, the principles enabled spending on research and development of new drugs specifically for conditions where the potential market was small (fewer than 200,000 affected individuals in the USA) and it was previously considered financially disadvantageous to fund research.

Market-driven economics under-supplied these drugs because low return on investment rendered them commercially impracticable. The 1983 Orphan Drug Act formalised the acceptance that increased human suffering was the result of market under-provision, and led to similar legislation in Japan (1993), Australia (1997) and the EU (2000). In the course of the legislation, Swartz (2006) claims national government "acknowledged that normal market practice can be dehumanising and oppressive, particularly for lower income people" and that "normal market practice is positively unconscionable when the people objectified as consumers are those AIDS victims who cannot pay for a life-extending, suffering-reducing medicine".

From the original US policy, the following special terms are applied to support the market provision of Orphan Drugs (Hayes 2001).

1. The developer is granted seven years of regulated monopoly on drug manufacture and marketing, in order to assist in recouping costs. In Europe, this period is six to ten years, dependent on profitability.
2. Up to 50 per cent of clinical trials costs can be refunded through tax credits.
3. The developer receives special assistance to aid protocol-compliance and the submission of Investigational New Drug applications.
4. Clinical trials can be further supported by grants of up to US $200,000 per year for a maximum of three concurrent years.
5. Product Licence Marketing Application fees are waived for Orphan Drugs.
6. Intellectual Property Rights for Orphan Drugs are transferable. In Europe this means that developers are free to market the same drug, outside Orphan Drug Scenario provisions, as they see fit and without restriction.
7. Shortened and simplified environmental assessments are acceptable with new drug applications and product licence applications.
8. Reviews are expedited for Orphan Drugs if conditions are serious or life-threatening, which leads to a reduction in approval lead-time.

The Orphan Drug Scenario provides a mechanism for centrally-funded supply of a commodity in the face of questionable return on investment through assisted private-sector provision. In the medical-ethics legislation the objective was to reduce human suffering by removing mitigating activities (positive externalities which are poorly reflected in market performance) from sales-led environments and making provisions for them using public policy instruments. This action is represented by Figure 4.2, vector B. There is scope for the implementation of similar solutions in other fields, although no legal or legislative framework is in place.

4.2.7.5. *Information Goods and Services*

Information Goods and services (zone 7) are characterised by non-rivalry and variable excludability depending on content, data policy and technological limits of usage. Digital Information is infinitely reproducible at almost zero marginal cost with perfect quality, and developments in global information networks and the Internet facilitate low-cost dissemination. Longhorn and Blakemore (2003) suggest that low marginal and distribution costs of geographical information goods do not obscure the fact that data is "very expensive to collect, process and maintain". In the public sector, costs must be borne through sustainable public taxation or other measures.

The translation of data, via information into knowledge through investment of intellectual capital is a central theme of Information Goods research. Although value-adding is commercially viable and "individuals have the right to be rewarded for their time and labour" (Stallkamp 2006), in some circumstances data transgresses into Merit Good because sometimes "the social value of information is ... much higher when it is widely shared" (Love 1994). Investment in value-adding permits individuals to claim ownership and thereby manage the property rights of products, as illustrated by Figure 4.2, vector A. As well as vector-shifts A and B, state-changes also occur. For example, introduced excludability can control information user-groups and transpose optimal management approaches from Information Good to Club Good territory. The existence of successful information markets depends on practical excluding devices such as Intellectual Property Rights (IPR), patents, copyrights and end-user licence agreements (EULA) to prevent market failure through excessive free-riding.

Non-excludability of Information Goods means that once data is released "into the wild", it is very difficult retrospectively to control or monitor consumption and duplication; this has led to the introduction of excludability instruments[8] which serve several purposes.

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[8] Excludability does not imply discrimination. There is no requirement for payment, but consumers must agree to a transaction of information before they are admitted to the user-

- Monitoring exploitation and maintaining usage audit trails
- Discouraging frivolous or unrealistic user-demands and abuse (Harris 2002)
- Validating provenance and quality of data for users
- Enabling community development among user-groups, leading to self-regulation
- Monitoring the efficiency of distribution channels
- Developing dialogue between supplier and consumer stakeholders

Many Information Goods can be effectively managed using strategies from other zones of Figure 4.2. The use of excluding devices to protect revenue causes a shift towards rivalry and Private Goods, with the implication that 'access keys' are provided only to paying customers. Similar devices that have no pecuniary element lead to a Club Good management regime complicated by a lack of crowding phenomena and potentially infinite club size. William Baumol (in Love 1994) categorised "information goods that are non-rival in consumption, but for which consumption can be excluded and controlled" as a separate category: Quasi-Public Goods. Here, the Baumol definition most closely applies to Club Goods. Where ethics render exclusion impracticable, Information Goods can be administered in three ways. As Public Goods they are centrally funded, non-excludable and non-rivalrous. As Orphan Drug Scenario goods, elements of Public Good value are widely accepted, and assistance is provided to ensure their provision through the private sector despite poor returns on investment in the marketplace. Finally, Merit Good scenarios provide a mechanism for central supply of a Good that would be under-consumed and neglected if subjected to market forces and individualistic choice, because of society-level non-market benefits.

Determining strategies for Information Good management, it is useful to discuss 'hard' and 'soft' excludability. Hard approaches employ excluding mechanisms to meter consumption of information or to rigorously control its

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group. When instruments of excludability are used there is overlap between Information and Club goods.

distribution. Typical approaches include watermarking of data (Lu et al. 1999, Kundur 2000), serial-number allocation, or licensing invoked to reduce lost opportunities of sale. Suppliers protect commercial advantage using legal instruments to secure revenue streams, enabling further research, development and profit. Outside commercial operations, stratified two tier pricing has been used successfully to introduce excludability and preferentially serve certain user-groups (ESA, NASDA and SPOT cited by Harris 2002). Note that pricing can lead to the commoditisation of Information Goods and their re-categorisation as Private Goods. Some suggest that any price introduces excludability (Kaul 2001), and that pricing of Information Goods must only provide a licence for use of data which remains the property of the acquiring or distributing body – as with some US data policies, shown Table 4.2. No ownership transfer occurs, so this approach avoids commoditisation and the associated complications of non-rivalrous products within the Private Goods Market.

Table 4.2 Rights and credits in Earth Observation data policy, as specified by the Japanese Space Agency (NASDA 1999)

Satellite	Data Right and Credit
ADEOS	NASDA retains ownership of the data
	NASDA supports author(s) in acquiring the data at marginal cost
MOS	NASDA retains ownership of the data
	NASDA supports author(s) in acquiring the data at marginal cost
JERS	MITI and NASDA retain ownership of the data
	NASDA supports author(s) in acquiring the data at marginal cost
TRMM	The US Government and NASDA retain ownership of the data
	NASDA supports author(s) in acquiring the data at marginal cost
Landsat	The US Government retains ownership of the data
	Space Imaging and NASDA support author(s) in acquiring data at marginal cost

Less restrictive approaches, often used for public sector information, include the member-list Club Good approach (as employed by the International

Charter for Space and Major Disasters) and logging of contact details for all users, as used in EROS Data Center File Transfer Protocol. Soft exclusion depends on consumer skills and capability. It is tempting to claim that Internet dissemination is non-discriminatory (Lu et al. 1999). It would seem that for as long as the network functions users can secure access, but this is not the case. Only qualified users who possess requisite technological, infrastructural and intellectual "keys" can benefit. For many potential consumers, barriers to entry are insurmountable because of nationality, socio-cultural group or income. Even when data is successfully acquired, necessary translation tools, such as processing software or intellectual capital may be chargeable or unavailable (Longhorn and Blakemore 2003).

4.2.8. General Markets for Geographic Digital Data

Clearly defined value-characteristics and public-private status form the basis for sustainable data policy, in turn influencing marketing and distribution strategy (Ito 2005). Love (1994) assesses pricing and distribution of digital government information, Helsley and Strange (1991) focus on the economics of excluding devices and Harris (2002) surveys pricing and distribution policies that have been implemented for digital geo-information. Table 4.3 illustrates a range of approaches.

4.2.8.1. Free Access

Free access management fulfils the demands of pure Public Good provision and ensures that barriers to entry are as low as possible, leading to commercialisation opportunities and unrestricted sector development. Peter et al. (2006) assert that "enhanced access to information supports the implementation of a sustainable development strategy" – for a long time a stated objective of CNES, ESA and other agencies. Under free access it is not possible to regulate data requests; transaction costs must be funded publicly and users may perceive that a price-less Good is worthless. Introducing elements of excludability into free access resolves some of these problems.

Table 4.3 Selected access control schemes for distribution of a Good. Asterisks represent club-good management approaches (adapted from Love 1994, Helsley and Strange 1991, Harris 2002)

Policy	Attributes
Free Access	No charge for data
	No membership fees
Non-cost Allow List *	Accredited users added to an authorised user list
	No charge
Coarse / Fine exclusion *	Membership fee payable
	Fine exclusion also incurs usage costs
Marginal / Incremental	Costs incurred in fulfilling the request for Good supply are met by user, known as COFUR
Tiered Access *	Fees depend on Public Good status of user
	Profit-making aims determine other prices
Encryption system *	Good is widely distributed
	A key is purchased to secure access
Full Price to All	Purely commercial provision
	Government assistance for Public Good activities

4.2.8.2. ***Allow-Lists***

Allow-lists were first proposed in 1971. The terminology is derived from Access Control Lists, used to enforce privilege separation across computer networks. They are acknowledged to be "the most general way to express protection qualities" (Lampson 1971, 1992) because only users on the list can consume the Good. User-group composition is recorded and individuals may be less likely to abuse a service if their behaviour is monitored. In addition, it is possible to 'moderate' the list of permitted users to ensure that only those with appropriate credentials or interests are served. Moderation improves value-for-money in terms of public expenditure by reducing wastage and facilitating user-feedback, subject to terms and conditions and privacy laws. A member-list develops sense of community or stewardship among users. Note that 'allow lists' do not necessarily include any pricing or fee structure. Reuters AlertNet and the International Charter for Space and Major Disasters (ICSMD) implement costless access lists for qualifying individuals or institutions. For ICSMD, a level of per-use authentication takes place, where charter activations are examined for validity before any action is taken. This form of non-commercial fine exclusion provides another layer of protection against frivolous or inappropriate use.

Price is the most common instrument of excludability. Helsley and Strange (1991) state that exclusion schemes where allow-list membership is chargeable form "coarse" exclusion. This approach allows revenue-generation and maintains the moderated lists of users, but does not allow control over resource exploitation. "Fine" exclusion permits more rigorous metering of resource use, but introduces new provider costs because it is potentially costly to monitor user habits and police their use of data. For resources such as digital mapping or geodata, extra costs incurred through fine exclusion may offset extra revenue, leading Helsley and Strange (1991) to conclude that for multi-dimensional data, coarse exclusion often allows profit-maximisation.

4.2.8.3. ***Marginal and Incremental Pricing***

When per-use pricing is used, as in most commercial data policies, Harris (2002) notes that agencies adopt differing definitions of marginal price, although it is generally considered to cover costs of reproduction and delivery. Love (1994) provides a considered definition: marginal price is the difference between the total cost of producing *n* Goods and the cost of producing *n-1*. Benefits of marginal cost provision are also examined by Love (1994), who states that "by pricing the good at the cost of producing the last unit the [marginal cost] rule ensures that output will expand until there isn't anyone who values the good enough to justify an additional unit of production". Marginal prices can be low enough to avoid impeding entry for new users, but also introduce user-investment, enforcing more considered data use and acting to limit abuse of data-provision services. In practice, the fixed costs independent of the number of consumers cannot be recovered using marginal pricing, and remain the responsibility of the data-gathering organisation. Economies of scale in information dissemination suggest that marginal price schemes under-fund this cost, leading to requirements for considerable public subsidy (Love 1994). Harris (2002) suggests that "for small datasets, and those accessed infrequently, the administrative burden of marginal cost recovery may outweigh the benefits of charging such costs, and data may be more efficiently provided at no cost".

Incremental pricing takes into account the large cost of serving the first consumer due to high implementation costs of reproduction and dissemination systems, and only aims to recover "cost of production that exceeds a certain level" (Love 1994). If government is accepted to be the primary data consumer, as suggested by Love (1994), Harris (2002) and Stallkamp (2006), incremental pricing reduces costs borne by late-entry consumers and facilitates the development of a value-adding sector.

*4.2.8.4. **Tiered Access***

Tiered access provides a stratified club-entry system for data use which allows differential treatment of categories of use or user. Returning to the conceptual model of the municipal swimming pool, concessionary pool membership could be granted. Swimmers in receipt of a state pension, or some other qualification, may attend at reduced cost but their usage is restricted to certain off-peak hours. For geographic information, tiered access enables widespread data use by the research community without financial barriers to entry, but preserves opportunities for sustainable market development and cost-recovery from commercial users.

Non-profit scientific data use contributes to knowledge and may produce environmental or humanitarian benefit-streams, so outcomes can be considered Merit or Public Goods to be funded through public taxation. In this context, provision of data at zero or marginal cost is appropriate (Harris 2002, Stallkamp 2006).

Commercial user's willingness-to-pay (and capability) is higher because data forms their raw product, processed and refined through investment of time and intellectual capital to provide revenue. Harris (2002) notes that tiered pricing introduces costs in much the same way as fine exclusion (Helsley and Strange 1991). Policing and monitoring of data use introduces ongoing administration costs which are only recoverable from commercial sales. Transitions between pure-science academic activities and those with marketable outcomes are rapid and difficult to define, so it is costly to identify transgressions of data policy. The development of complex and legally precise data policies introduces implementation costs which must also be recovered.

4.2.8.5. ***Encryption***

Hard and soft exclusion are used in television broadcast technology. For soft exclusion, failure to present a valid licence for receiving equipment is a crime but the licence does not allow reception - unlicenced users who possess receiving equipment can receive pictures at the risk of legal penalty. Hard exclusion stops users from free-riding in this way by preventing unlicenced consumption of the good. For broadcast satellite TV this typically takes the form of a smartcard programmed with a unique identification number, linked to a subscription database. The card, in conjunction with a receiving device, is permitted to receive only channels which have been paid for. In the example of television, non-rivalrous broadcasting is a fixed cost (depending on coverage), and excludability is decided by data policy and corporate strategy. Other types of broadcast data could be managed in this way, assuming broadcast and dissemination is not costly or rivalrous: assumptions that hold true for many intangible information goods.

The only operational use of encryption in Earth Observation is Eumetsat, which for several years has controlled access to time-critical data types using digital keys which are no longer required three hours after data acquisition (de Selding 2006, NOAA 2006). Data becomes free-access once the three hour window has expired. De Selding (2006) notes that this European policy does not correspond with the US approach, largely established following a failed attempt to commercialise Landsat in the mid 1980s (Stallkamp 2006). "Data access to meteorological satellites has long been a source of disagreement between the US and Europe, with Europe opting to commercialise some weather images and the US taking more of a free-access view" states de Selding (2006). In fact, security legislation may exert the largest influence over encryption. Hard exclusion approaches developed to support the European business-model are currently the subject of proposals by US defence agencies and NOAA which aim to prevent access to meteorological data for "blacklisted" regions and organisations (Eumetsat-NOAA Data Denial Agreement 2006). Exclusion of this type can co-exist with tiered pricing and marginal pricing because computer key-making technology is now sufficiently advanced to enable the exclusion of specific dates or geographical regions for individual users in near-real-time (NOAA 2006).

Harris and Browning (2005) discuss issues of hard exclusion and "access-key pricing" and conclude that widespread dissemination of encrypted data could benefit Earth Observation as a discipline in the light of developments in data delivery and on-line services. In addition, the purchase of costly keys with pre-defined scope would focus attention on the information-content of data and its utility for specific projects and activities. Although encrypted delivery schemes offer clear benefits for service providers and consumers, three potentially problematic issues are identified (Helsley and Strange 1991, Love 1994, Harris 2002),

- Developing, policing and monitoring hard exclusion mechanisms is costly and technically challenging. Significant ongoing costs require a "step change" in investment
- Very large volumes of encrypted data must be transmitted to ensure availability to key-holders (and for high-volume high-resolution data, on-demand delivery to authenticated users may provide a solution)
- User-groups and organisations may not be equipped with requisite technology and installation is costly (NOAA currently charge US $900 for a Eumetsat PDUS receiver, excluding decryption key, Stallkamp (2006) refers to PC-based solutions for US $500)

4.2.8.6. Full Market Price

Schemes of exclusion can be based upon group-membership, authentication or price, but none offer recovery of expenses without significant public funding - with the exception of competitive market pricing (CMP). The CMP of a data product includes research and development costs, instrument construction costs and implementation or launch fees. Ground-segment and marketing costs, operator profit and the research and development of next-generation products are also captured by competitive market price, which manages Earth Observation as a private, marketable commodity. Support for value-adding companies in the space industry has traditionally come from government, both in terms of direct financial support and from tenders aimed at meeting government requirements. In the UK and Europe, secure government funding for space has decreased in real terms over recent years (Bawler et al. 1998, Saul 1998), so operators aim to commercialise operations and maintain sustainable growth that is *independent* of government. The only space sector yet to achieve this target was telecommunications in 2001 (ESA 2002).

At a conference entitled 'New Space Markets', Hieronimus-Leuba and Willekens (1998) stated that "the European space community is today facing a turning point: the sudden need, anticipated by some but not all, to steer away from a familiar safe course and negotiate a fast and hazardous stretch which will lead to renewed stability". The benefits of sustainable commercial growth in Earth Observation include a more user-focused data-supply chain, recovery of all investment costs and independence from government funds.

For some user categories, barriers to entry imposed by competitive market pricing may be prohibitive, limiting scientific and research exploitation of data sources. Following full commercialisation, research work funded as a Merit or Public Good would be reliant on high-cost purchased data. Increased cost of publicly-funded research would offset savings from the commercialisation process. In addition, commercially-led data supply "fails to recognise the need to invest in space for scientific and humanitarian returns as well as for operational and commercial benefits" (Harris 2002) and does not provide a mechanism to supply necessary information for governance in the event of changing environmental legislation such as 6EAP and GMES. Retaining publicly-funded capability may therefore have strategic importance. It is helpful to note here that tiered access, no-cost 'allow lists' and competitive market pricing are not exclusive, but could hypothetically co-exist within a hybrid data policy.

4.3. Earth Observation- the Unknown Good?

The publicness of Earth Observation data resides in two dimensions – rivalry and excludability, illustrated by Figure 4.2. The diagram can be populated with coordinates that represent sources of Earth Observation data and their embedded or embossed publicness, Figure 4.3. It is clear that publicness of Earth Observation data sources is widely variable and that designing general data policies may be inappropriate and unrealistic. In addition to the generalised characteristics illustrated, the status of Earth Observation data changes over data life-cycle and in response to world events. Hybrid data policies which integrate several components of Table 4.3 are more likely to effectively address variable data properties.

Table 4.4 Key to data sets mapped in Figure 4.3. Details of categories of Good are discussed in more detail in the following text.

Location	Earth Observation Data Type	Category of Good
1	Meteorological Data	Public Good
2	Landsat (all sensors)	Public / Merit Good
3	NOAA AVHRR	Merit Good
4	Envisat ASAR	Quasi-Private Good
5	SPOT (all sensors)	Quasi-Private Good
6	Radarsat SAR	Quasi-Private Good
7	Google Earth	Club Good
8	ICSMD Data	Club Good
9	VHR Optical Data (Ikonos / Quickbird)	Information / Private Good

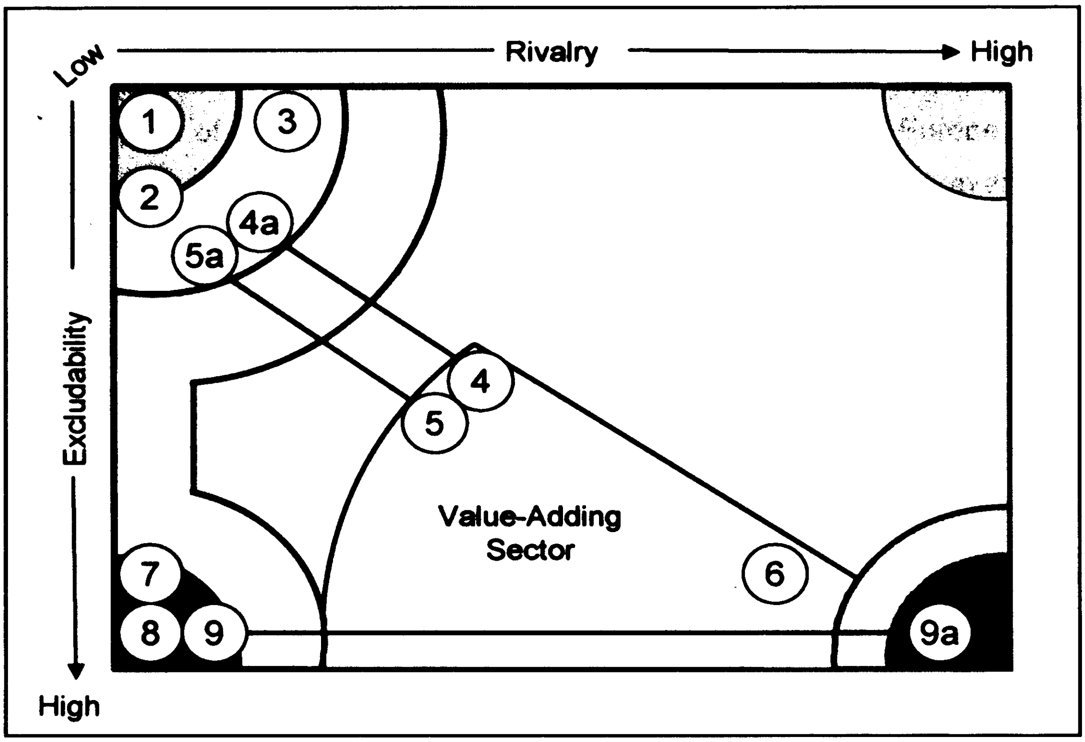

Figure 4.3 Populated landscape of Goods in Earth Observation – development of Figure 4.2. Note the inclusion of the value-adding sector within Earth Observation activities. Although ASAR (4) and SPOT (5) data normally reside within the commercial sector, under some circumstances data is provided under Merit Good conditions, illustrated by annotations 4a and 5a. VHR optical data is managed as a Club Good (9) or as a Private Good (9a), depending on spatial coverage, the identity of the consumer and the planned data exploitation.

4.3.1. Earth Observation Goods and Data Types

4.3.1.1. Meteorological Data

With the exception of data less than three hours old from Eumetsat, weather satellite data is available "to every interested user, free of charge on an unrestricted basis" in line with World Meteorological Office recommendations (Weiss 2002, Eumetsat 2006). Some technical and socio-cultural exclusions still apply, but as far as possible for the provision of digital information, data is non-excludable. Because digital sources of information can be reproduced infinitely with no loss of quality and users receive a perfect duplicate, meteorological data appears non-rivalrous[9]. Data can be freely provided in this way because "the costly ... satellite programmes are funded by the contributions of its Member States and Cooperating States" in Europe, and because in the USA "taxpayer-funded information is made available inexpensively and as widely as possible" (Weiss 2002, Eumetsat 2006). Once platforms for data acquisition and distribution mechanisms are in place the marginal cost of data falls very rapidly to approach zero. Tadesse (1998) notes that in Africa "the dissemination of environmental information from meteorological satellites has been realised to be cost-effective and efficient". A degree of free-riding is encouraged by administrative bodies because increased use does not incur costs, yet leads to societal benefits through Merit Good effects (Stallkamp 2006, Tadesse 1998).

In less developed nations, Eumetsat addresses problems of access in its Data Policy, stating that the organisation "supports the national meteorological services of less wealthy countries by granting access to all of its data free of charge" (Eumetsat 2006). This support is interpreted as "positive discrimination" by von der Dunk (2002), who comments that meteorological activities have been the subject of intense commercialisation in recent years, captured in changes to Eumetsat policy that introduce fee-structures to meteorological services using data for commercial purposes outside "Official Duty Use". Meteorological data greater than three hours old is the purest Public Good of Earth Observation data currently available, due to characteristics of extensive non-excludability and non-rivalry embedded in digital format and embossed through data policy. Separation from the upper-left origin of Figure 4.3, however, denotes the fact that few goods are entirely pure (Georgiadou and Groot 2002).

[9] Is data rivalrous if many users simultaneously request the same data from a server? Because the rivalrous resources in this situation are processing power and network bandwidth, the data remains non-rivalrous. No user may monopolise the original, regardless of network traffic.

ESA stated in 2002 that there is little commercial value in meteorology because it is primarily funded through civil programmes, yet "more accurate weather and climate forecasts contribute to wellbeing and the economy by reducing risk and creating new opportunities" (Williamson et al. 2002). Even data provided as Public and Merit Goods can bring indirect economic benefit. When improved weather information brings cost reductions, savings are directly attributable to the meteorological data. 'Inheritance' of value through reduced uncertainty and increased capability is revisited in section 6.4.2.2. An alternative way of valuing the benefits of improved weather prediction is raised by Williamson et al. (2002):

> If we recognise that the US government is going to perform weather research (and operate weather data and forecasting centres) indefinitely into the future for military, strategic and public safety reasons, and if we also recognise that most of the data will be disseminated to the public at little or no cost, then there is only the question left of how much *additional* money the government should spend on improving *civilian* forecasts (Williamson et al. 2002)

The socio-economic effects of improved weather and climate forecasting are wide ranging, but incompletely considered in civil remote sensing budgets justified using Cost-Benefit Analysis. Several recent meteorological programmes have aimed to include indirect market effects in analyses, but little assessment of non-market impacts has been made.

Numerical weather prediction (NWP) modelling with remote sensing data began in 1969, when Numbus-3 Satellite Infra-red Spectrometer (SIRS-A) data was first included to improve predictive accuracy in the Southern Hemisphere, where *in-situ* measurements were sparse (Ohring et al. 2002). Currently the US National Centre for Environmental Prediction (NCEP) relies on remotely sensed data for 83 per cent of model initiation conditions; despite this "it is fair to say that satellite data are currently underutilised and that a concerted effort is required to realise the benefit of the world's large investment in satellite deployed instruments ... [furthermore], next generation sensors will provide data with accuracies and time and spatial resolutions never before achieved" (Ohring et al. 2002).

In late 2002, the US National Aeronautical and Atmospheric Administration (NOAA) conducted a weather sensitivity study in support of the GOES-R Sounder and Imager instrument, to quantify the effects of improved weather information in the US. The report concluded that 20 percent of the US economy is weather-sensitive, representing a dollar value of US $2 trillion.

Estimates of the financial benefits of improved weather information include:

- Two-thirds of all US air carrier delays are caused by adverse weather, with a financial impact of US $4 billion per year, of which US $1.7 billion is avoidable. Additional fuel savings of up to US $7 million per year can be expected if improved weather information is used to inform airline fuelling (Leigh 1995, cited by Williamson et al. 2002).
- Floods, storms, fire damage, drought and other weather factors led to the loss of US $9 billion of crops in 2000 (NOAA, 2002).
- Ross and Lott (2000, cited by Williamson et al. 2002) estimate that in the decade 1990-2000 the east coast of the US suffered losses of approximately US $58 billion, some of which could have been avoided with more accurate global analysis and short-range forecasting.
- Improved frost predictions (primarily for fruit growers) and weather information for irrigation planning could save US $50 million per year in agriculture (Williamson et al. 2002).
- If hurricane predictions in the Gulf of Mexico could be improved by 50 per cent, drilling platform operators would see cost reductions of US $15-18 million per year, based on fewer costly evacuations of personnel (Considine et al. 2004)
- Finally, the ability to more accurately predict and more effectively manage electrical power requirements of the US National Grid could save US $479 million per year in surplus power generation caused by inaccurate demand models. Better weather data could also reduce power cuts and shortages when demand has been underestimated (NOAA, 2002)

Alongside NOAA estimations, the €20 billion Meteosat Second Generation (MSG) programme has driven similar impact assessments in Europe, which conclude that MSG "will significantly enhance the observation capabilities for rapidly changing phenomena ... [to] help nowcasting, short range forecasting and numerical weather prediction" (Schmetz et al. 1999). These effects are based on a new 15 minute global repeat cycle, more rapid data downlink, and improved sensor performance (including an unprecedented multispectral capability).

ESA (2007) state that "this service [MSG] allows us to plan our lives with more accuracy: skiing, sailing, walking, climbing, cycling, outdoor games, domestic gardeners, decorators and holiday makers - best of all, it's free!"

More detailed benefit-cost assessments of MSG include:

- Improved weather forecasting for construction and civil engineering leads to savings of €40 million per year. This saving captures improved efficiency and planning accuracy for key operations such as groundwork and concrete pouring.
- Transport networks can be managed more effectively if problems such as ice, snow and high winds are more accurately predicted. Wastage and the environmental impact of salt and de-icing chemicals is reduced with more complete and timely meteorological data, and the threat to human life is minimised. When opportunities for more efficient aircraft routing are considered, ESA estimate savings of €30 million per year from direct savings, reduced fuel bills and fewer insurance claims.
- Just as in the United States, European energy production is linked to demand forecasts, updated every 30 minutes using meteorological data. For business intelligence and efficiency management, Schroedter-Homscheidt et al. (2005) identify relevant features of MSG; "Meteosat-8, with its carefully selected 12 spectral channels, allows not only much more precise characterisation of clouds, but also retrieval of atmospheric water vapour, ozone and partly aerosols. Knowledge of these components allows ...real-time radiative transfer

modelling for solar irradiance estimates". ESA (2007) estimate that improved forecasting has reduced European energy requirements by 3 per cent, and decreased costly over-production, previously caused by inaccurate demand models. This leads to savings of €11 million per year.

4.3.1.2. ***Landsat***

Landsat data policy reflects dual objectives of US remote sensing: to distribute federally-collected data free or at minimum cost, and to support the development of a sustainable and varied value-adding sector (Love 1994, Thompson 2000, Harris 2002, Weiss 2002). The policy refers to the "cost of fulfilling user requests" (COFUR) as an incremental pricing structure, not the marginal-price model implemented by other suppliers and previous policies. Operating costs and the burden of supplying the first user are borne by federally funded satellite operators. When first-user governmental activities wholly justify expenditure, subsequent third-party use is of negligible additional cost, so incremental pricing suggests that unenhanced digital data can be provided through on-line channels at almost zero cost (Love 1994).

Setting aside issues of soft exclusion, which are difficult to overcome and reside beyond the scope of even federal data policies, the Landsat model aims for non-excludability and the provision of data "on a non-discriminatory basis" (Harris 2002). Referring to Figure 4.3 label 2, Landsat excludability appears variable, which reflects costly elements of provision funded by federal budgets. The commercial development of instruments competitive with Landsat transposes the Good from Public to Merit in status under some circumstances. The viability of commercially-funded satellite sensors has only emerged in the years since the Landsat programme began.

The extent of rivalry in Landsat data policy is quite clear: it is stipulated that any enhancement or value-adding activity outside the governmental remit is conducted in the private sector (Harris 2002) and is chargeable commensurate with investment of time and intellectual capital, on a commercial basis (Stallkamp 2006). Although there may be apparent rivalry between end-product consumers, this is competition for the time and energy of value-adding personnel, which are excludable and rivalrous resources. Tasking and provision of data "to-order" are not possible with Landsat data and archives are digital and accessible; these elements suggest that Landsat can be considered a non-rivalrous resource supplied by a government fully cognisant of externalities, as a Merit Good in support of the national economy and strategic position.

4.3.1.3. ***NOAA AVHRR***

The Advanced Very High Resolution Radiometer (AVHRR) operates in polar-orbit at 833km altitude and collects environmental data in five spectral bands. The sensor samples at 1.1km or 4km ground pixel resolution. Global coverage is available four times per day using two POES (Polar Orbit Environmental Satellite) platforms. The complete AVHRR data archive covers the period May 1978 to present, and it is available on-line through CLASS (the Comprehensive Large Array-data Stewardship System), which delivers over 65,000 data products per month (NOAA 2006). Aligned with Landsat data policies AVHRR is priced incrementally; digital delivery is free of charge, optical media are US $25 per data unit, and magnetic media are US $100 plus handling to reflect increased costs of fulfilling user requests (NOAA 2006). In terms of excludability, NOAA data are distributed on the same "non-discriminatory" terms as Landsat products. They can be considered non-excludable for the purposes of categorisation and management.

Some AVHRR data exhibit rivalry in consumption. Users who require specific area coverage at 1.1km HRPT (High Resolution Picture Transmission) ground pixel resolution have two options. If a receiving station is based within the satellite transmission footprint, it may be possible to receive direct-broadcast HRPT data. For guaranteed delivery an application must be made for NOAA to schedule on-board data storage through LAC (Local Area Coverage). NOAA warn that "because recorder space and transmission time must be shared by many requestors, requests must be received at least one month prior to data acquisition period [and] will be considered on a first-come first-served basis" (NOAA 2006). Due to high LAC coverage demand, the following situations are prioritised.

- National emergencies
- Situations where human life is endangered
- US Strategic requirements
- Commercial requirements
- Scientific investigations and studies
- Other miscellaneous activities

Limited LAC coverage introduces rivalry based on satellite capacity, in a way that appears comparable to SPOT programming. One difference is that LAC users cannot join a 'club' to expedite their requests. This is because AVHRR is a national resource managed by NOAA, representing stakeholders, users and the interests of the funding public. Rivalry alters the position of AVHRR within Merit Good territory, towards Common Pool status. To use an example, many academics compete for LAC storage and transmission. The scientists, who are stakeholders working in a Public Good capacity, must compete for a finite resource which is rivalrous but non-excludable.

The categorisation of AVHRR as a Merit Good (Figure 4.3, label 3) represents a change from its original Public Good status. Technical, political and financial barriers to entry in the late 1970s meant that only governmental satellite provision was viable. It is now demonstrated that commercial Earth Observation business models can succeed, so continuing provision of AVHRR data fulfils national strategic and human-benefit requirements as *non-market* externalities, the effects of which justify ongoing expenditure.

4.3.1.4. ***Envisat ASAR***

The objectives of ESA Earth Observation data policy fundamentally differ from those of American missions, illustrated by Envisat and the ASAR (Advanced Synthetic Aperture Radar) instrument. The Envisat Data Policy was developed in 1997 and 1998 following eight years of ESA experience managing the ERS-1 and ERS-2 satellites (Kohlhammer 2001, Harris 2002). Prior to the launch of ERS-1, ESA identified three potential consumer groups:

scientific users, commercial users and the meteorological community. The ERS policy established that contracts between receiving stations and research entities provided data for scientific use, and ESA Announcements of Opportunity facilitated the development of new applications, products and services. A distribution consortium was licenced to supply commercially processed data at a pre-defined tariff which incorporated a profit margin to reflect the requisite investment of time and intellectual capital. Kohlhammer (2001) states that prices "depended on the processing level, the product type and the delivery medium and ranged from €250 for a medium-resolution Synthetic Aperture Radar (SAR) scene to more than €2,000 for a terrain-corrected geo-coded SAR product covering 100x100km."

After three years of operation a lower tariff was introduced in 1994 "to foster better cooperation with the science community", which accounted for less than three per cent of 1992 sales (Kohlhammer 2001). Although scientists used ERS data, prices were a significant barrier to entry, and many projects were facilitated only through Announcements of Opportunity. The 1991 ERS data policy relied on price-based exclusion of a quasi-private Good, which neglected a significant component of the user-community and did not provide scope for non-market exploitations outside the coverage of Announcements of Opportunity.

The Envisat data policy was designed to follow and replace ERS policies, addressing shortcomings and providing a flexible approach "adapted to the latest ideas for funding Earth Observation missions and their exploitation, and to the policies of other (non-ESA) Earth Observation missions" (Kohlhammer 2001). The key objectives, as ratified in 1998, were to maximise beneficial use of Envisat data and ensure that ESA mission objectives were achieved. Five key differences were introduced in the transition from ERS to Envisat policy:

(1) A two-tier categorisation of use was introduced to replace the differential treatment of users that caused discrimination under ERS policy. Category 1 projects include research and applications

development, long term Earth-system science, activities preparing for future satellite use and internal validation and quality assurance (Petiteville et al. 2001). Category 2 use includes all activities beyond the scope of Category 1 – such as operational and commercial use.

(2) Category definitions are integral to the Envisat policy document, which aims to consistently price all projects, whether proposed and administered by private companies or academic researchers. Cost of reproduction can also be waived for certain applications, if approved by the Earth Observation Programme Board (Kohlhammer 2001, Potin 2006). Usage-groups are separated. ESA fulfils Category 1 requests internally and Category 2 is delegated to appointed distributing entities operating in the open market.

(3) Two global distributing entities are contracted to undertake market development, conduct service delivery reviews and maintain investment commitments (Kohlhammer 2001). Distribution rights overlap to maintain competition and motivate good service for consumers.

(4) Distributing entities set Category 2 data prices according to business plans or market behaviour, although use of the term Full Market Price is misleading because distributing entities do not recover fixed-costs or directly finance next-generation sensors. Kohlhammer (2001) notes that distributors may appoint niche-market specialist distributors in due course. For Category 1 use prices are set slightly above COFUR, although in some circumstances data can be provided entirely free of charge.

(5) It is permissible for distributing entities to approach High Resolution Picture Transmission receiving stations and compose distribution agreements with the objective of broadening the availability of data products to consumers. Potential local or regional data markets can also be developed through this mechanism.

Harris (2002) states that the Envisat tiered-access policy allows "flexibility for market development and at the same time protects legitimate research use of Envisat data". Paying the incremental price and dealing with ESA directly, users in Category 1 are exempted from market activities but are still subject to some price-based exclusion (Figure 4.3, label 4a). Kaul (2001) notes that even a cheap good remains inaccessible to those without funds. Addressing this price-exclusion, the Earth Observation Programme Board authorise fee-waivers for projects in support of agency objectives or Announcements of Opportunity such as the Tiger Africa initiative (ESA 2006). Under the waiver, registered investigators are allocated a quota of data, e.g. 200 ASAR scenes, and all tasking and programming is free of charge. Qualification excludability applies to Category 1 use goods because users must comply with restrictions to avoid transgression of Category 1 boundaries. Although strict usage restrictions seem to impose mandatory club membership on consumers (commercial or operational use is forbidden) this is not the case because the data policy separates "user" from "use", so even the most Public of Envisat Category 1 applications conform to Merit Good status.

Activities of Category 2 consumers are more excludable based on price and availability. They reside in the value-added sector of Figure 4.3, represented by label 4. Individual data products are positioned along the line between Figure 4.3 labels 4 and 4a, depending on the category of use, labour-intensiveness of their production and their supply and demand characteristics.

Envisat data policy does not address rivalry directly, but considers that non-exclusive licensing allows non-discriminatory access, insofar as "nobody in the world can obtain ... data alone while restricting its use to anyone else" (von der Dunk 2002). This appears to acknowledge the basic non-rivalry of distributed digital goods. For ASAR it is noted that radar-based Category 2 uses are likely to require more detailed expert intervention than optical data, increasing potential rivalry. Processing streams are more complex and technically challenging; greater investment of time and intellectual capital is reflected in the higher price of radar products. If distributors allocate sufficient resources for processing of this data, rivalry in time-allocation is offset against greater excludability through price because investment in staff must be accounted for, assuming profitability is constant. Radar products under Category 1 use are also more rivalrous than their optical counterparts because greater intellectual and technical requirements increase 'soft' exclusion and reduce the number of individuals capable of effectively using data. In real terms 'soft' exclusion is not a major consideration for ASAR because individuals who qualify for Category 1 use are likely to posses required technical skills and Category 2 use-groups include operational and commercial entities capable of overcoming greater price-exclusion to acquire complex data.

Significant commercial data supply through distributing entities and value-adding companies, ASAR is considered a quasi-Private Good. Some Public Good activities are supported by Envisat and ASAR, but only 15 per cent of total sales are through the Category 1 mechanism (Kohlhammer 2001), so this forms a secondary benefit-stream. It is theoretically possible to acquire ASAR data as a Merit or Public Good, but only with Earth Observation Programme Board approval, and in support of ESA research and development objectives.

4.3.1.5. ***SPOT***

SPOT began in 1978 as a collaboration between Belgium, France and Sweden with the objective of launching a sun-synchronous polar-orbiting Earth Observation satellite platform. With cross-track pointing, every location on the Earth's surface could be imaged every two and a half days with a panchromatic ground pixel resolution of 10 metres, and multispectral coverage at 20 metre ground pixel resolution. Pointing allowed locations to be revisited from different viewing angles, and stereoscopic image pairs were used to generate digital terrain models (DTMs).

Mouysset (1998) confirms that there was no intention of marketing SPOT-1 data; SPOT-2 was planned as a market-sustained sensor to be launched in 1981. It was claimed that ongoing funding security could be guaranteed if sales revenues covered costs, but this was unlikely at the time: "the size of the market was very limited, because the use of such data was scientific ... it was necessary to develop the market" (Mouysset 1998). A commercial company called SPOT Image was set up in 1982 to undertake marketing and data dissemination. By 1998 the initial market-development of SPOT Image was complete and Mouysset (1998) states that "all operational costs [were] covered by sales revenues; in particular, satellite control costs borne by the Centre Nationale d'Etudes Spatiales [(CNES) were] reimbursed". Within commercial remote sensing, CNES and SPOT validated a market-pull business model, which new competitors have employed. 60 per cent of SPOT revenue is from mapping and agriculture sectors, where other sensors and operators, such as Landsat, could not supply adequate ground pixel resolution or temporal coverage. As commercial remote sensing grows, this may change. Comparing SPOT to an unequivocal Private Good, Mouysset (1998) states that "the cake will be shared by more, but it will also be bigger." This optimism is not shared by Rosenholm and Harris (2002), who assert that "SPOT Image [commercial] data sales have virtually stagnated". In an interview in the journal *Directions*, SPOT Image CEO Jean-Marc Nasr acknowledges a shift in market positioning, affecting the SPOT business model: "There is no significant 'commercial private' market as we thought in the 1980s, certainly not enough to sustain or support data providers ... this market is dominated by defence and security and will remain that way for the next five to 10 years" (*Directions*, 1st January 2005).

SPOT data initially appear to reside entirely within the zone of Private Goods, thanks to price-based excludability and rivalry for satellite pointing and subsequent data processing. However, this is not the case because a new agreement provides SPOT data as a Merit Good (illustrated by Figure 4.3, label 5a). ESA and SPOT Image aim to supply 10,000 SPOT products per year for Category 1 uses[10]. A significant number of consumers working outside operational or commercial fields will gain access to SPOT data for the first time. ESA (2006) state that "besides its commercial activities the company [SPOT Image] has a mission to promote the use of satellite images; the agreement with ESA giving easy access to the SPOT data encourages the scientific community to get involved in the space sector".

[10] Category 1 is determined using the same criteria as for Envisat data.

4.3.1.6. *Radarsat SAR*

The Radarsat-1 satellite programme is administered by the Canadian Space Agency (CSA) in association with US government departments (NASA and NOAA) and Canadian provincial administrations. The data policy shares some elements with Envisat and Landsat 7 approaches, with the addition of cost-recovery mechanisms beyond incremental or marginal pricing[11]. A private company named Radarsat International[12] was established following the launch of Radarsat in 1995 "under contract to the CSA to process, distribute and market Radarsat data to the user-community" on a quasi-commercial basis. The objective was to recover operational costs through data sales in the same way as SPOT Image (Jackson et al. 1996). The CSA licence agreement installed RSI as sole agents, and allowed the company to set market prices and recruit local distributors under exclusive terms. Harris (2002) notes that this breaches "the non-exclusivity which figures so prominently in both ESA's and the Landsat 7 data policy".

The Radarsat-2 mission is administered as a public-private partnership between CSA and MDA. Brûlé et al. (2004) comment that "under agreement with the CSA, MDA will own and operate the satellite ...the CSA's investment will be recovered through the supply of imagery to Canadian Government user departments during the lifetime of the mission". In line with US policy, the satellite will be subject to Canadian 'shutter control' for the purposes of governance and national security.

Several reports draw attention to inflexibility and discrimination of Radarsat pricing under MDA. AthenaGlobal (2006), reporting to CSA, comment that "traditionally, access to data from science-focused missions has been free-of-charge and relatively straightforward [under ESA and US data policies]. By

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[11] Special arrangements exist to permit the acquisition by NASA of a limited amount of Radarsat data at no-cost. These so-called pre-purchase agreements relate to launch costs incurred by NASA during the Radarsat programme. Precise details of this arrangement fall outside the scope of this discussion.

[12] As of 2004, Radarsat International is a subdivision of MacDonald, Dettwiler and Associates (MDA)

contrast, data from Canada's Radarsat is only available at a cost, and federal government users pay different rates from other users". Jackson et al. (1996) state that "The RSI 'one price-list fits all' policy may not be optimised to the situation in which there are very different kinds of users" and they refer to an example: a commercial mapping company can express much larger willingness-to-pay for a radar scene than a scientific ice monitoring programme. The commercial user derives ongoing benefit from the scene and uses it to generate revenue, but ice-monitoring data is highly perishable and the image is only useful for a short time. This is reflected in a much lower willingness-to-pay, yet both consumer-groups are exposed to the same market pressures and price-based excludability. Jackson et al. (1996) conclude that Radarsat data policy "creates significant obstacles to the creation of a viable market for operational use of Radarsat data in the US". Radarsat data is therefore highly excludable for all users, based on price.

In addition to issues of price-based excludability, Radarsat data is rivalrous because of a wide range of modes, processing levels and satellite tasking options. Fifteen priority levels and seven core products are offered by Radarsat (excluding polarisation options); each is priced according to beam mode, level of processing and urgency of delivery (Jackson et a. 1996, Brûlé et al. 2004). Price determined by processing level compensates MDA for investment of intellectual capital, but the introduction of rapid-turnaround data for a higher fee introduces formal competition, or rivalry, between consumers. This is equivalent to a queue-jumper's premium.

A brief examination of prices illustrates these issues. Radarsat standard-mode (25m) data, covering 10,000km^2 and processed to precision map level cost US $3,500. Guaranteed image acquisition within 29-60 hours of request carries a premium of US $1,000, and standard processing costs US $100. Data processing and delivery within six hours of reception costs a further US $1,000. Users expressing very high willingness-to-pay can therefore expect data delivery within 66 hours of request at a charge of US $5,500. The cheapest option for acquiring the same data is US $3,600, with no delivery time constraints (RSI, 2006). For qualifying Category 1 uses, similar specification Envisat ASAR data costs as little as US $25, and commercial data acquired through a distributing entity attracts a price of US $2,000 (Kohlhammer 2001). The extra expense of Radarsat data increases excludability, and the imposed rivalry of queue-jumping options means that Radarsat data are clearly private goods distributed through the value-adding sector (Figure 4.3, label 6).

4.3.1.7. ***Google Earth***

Google Earth is an application that can be downloaded free of charge, which permits the exploration and display of geographic information via an Internet connection. The data is collated from over 100 sources including commercial remote sensing satellites and NASA. The application allows users to view a global data catalogue which is centrally processed and managed by Google. Third-party copyright watermarks appear on each image and datasets are tiled automatically, as shown in Figure 4.4. No specialist knowledge is required to navigate through images and it is possible, using a simple interface, to superimpose additional information such as terrain, road networks and national borders. Google Earth has been popular with Internet users – the software was downloaded over 100 million times in the first year of availability (*SpaceMart* 2006). Despite this popularity, Randerson (2006) states that "for most of us, it is a quirky desktop toy for checking out our house or a few world landmarks from space".

It is not possible to store, modify or interrogate data presented through Google Earth and streamed images are JPEG compressed, causing data loss and reduction in quality. The satellite images accessible through GE are one-dimensional[13], non-transferable and contain no metadata. Because of lost data integrity the images are of symbolic value only. They can be readily interpreted, but are of little use from a scientific perspective, except for orientation or navigation. Outside the scientific community, Google Earth has become a key dissemination tool for geospatial information. Although some

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[13] No 'feature' information is present and it is not possible to alter displayed wavelengths. Pseudo-true colour composites are most commonly supplied.

way short of a GIS, the application provides a flexible visualisation system that suits the needs of public-facing government agencies, natural hazards workers, humanitarian aid organisations and NGOs. Google Earth data has been distributed by the US Forestry Service for wildfire monitoring (at http://activefiremaps.fs.fed.us/wms.php) and by aid agencies to expose the humanitarian crisis in Darfur (at http://www.ushmm.org/googleearth). The software has also been used, in conjunction with updated imagery provided by Amazon, for missing person searches in large and inaccessible areas (BBC, 10th September 2007).

Figure 4.4 The Google Earth interface, showing image tiling and embedded watermarks in the area surrounding Cape Town, South Africa (© Google Inc. 2006)

It may seem that Google Earth is non-excludable and non-rivalrous as a resource; it is freely distributed over the internet, and consumers cannot compete with each other in its consumption. However, excludability is introduced in the form of a legally-binding licence agreement. Some terms from the agreement follow.

> By installing the software ... you are confirming your acceptance ... and agreeing to become bound by the terms of this licence agreement ... if you do not agree to the terms, please do not download the software.
>
> This software is for non-commercial use only and your rights in the software are strictly limited to home, personal or recreational use only by you and not for the benefit of third parties.
>
> You shall not copy, reverse-engineer, decompile, disassemble, translate, modify or make derivative works of the Software, geographical information, screen outputs or prints in whole or in part (Google Inc. 2006).

To use Google Earth, consumers enter into a compulsory agreement with the Goods provider. If the agreement is unacceptable then the provider declines to supply the Good. In this way Google Earth is managed as a club with non-cost membership criteria, shown Figure 4.3, label 7. Excluding devices are used to ensure rule-compliance among users, fair use and to protect the intellectual property of developers.

Following the success of Google Earth, the French national mapping agency (IGN) introduced a similar web-based mapping portal called GéoPortail, covering all French territories at high ground pixel resolution. Demand for the service was so great that only twenty per cent of users were served in the first few days due to network saturation. IGN stated that "if the exceptional level of traffic to the website continues, the promoters may need to regulate access to the site, probably on the basis of passwords" (*SpaceMart* 2006). The introduction of non-cost exclusion introduces a sense of common membership and responsibility, reducing the likelihood of service abuse. Referring to Category 1 uses, ESA state that "a number of products have been specifically developed for availability on Internet servers in near-real-time. Such products are made available at zero cost; nevertheless *access to this data is controlled and monitored*" (my italics, ESA 2004). Even without costly membership, geospatial data can be effectively managed as a Club Good.

4.3.1.8. ***International Charter for Space and Major Disasters***

The International Charter for Space and Major Disasters (ICSMD) was established in 2000 to provide a policy mechanism to supply processed satellite data for the management and mitigation of natural or technological disasters which cause "loss of human life or large-scale destruction of property" (ICSMD 2004). The Charter was ratified at the 1999 UNISPACE III conference in Vienna by three founding agencies. Membership has expanded to include the following agencies and sensors.

Table 4.5 Participating agencies and sensors available through the International Charter for Space and Major Disasters

Participating Agency	Satellite Sensor
European Space Agency (ESA)	ERS, Envisat
French National Space Agency (CNES)	SPOT
Canadian Space Agency (CSA)	Radarsat
Indian Space Research Organisation (ISRO)	IRS
U.S. National Oceanic and Atmospheric	POES
Administration (NOAA)	GOES
U.S. Geological Survey (USGS)	Landsat
Argentine Space Agency (CONAE)	SAC-C
Japanese Aerospace Exploration Agency (JAXA)	ALOS
British National Space Agency (BNSC) on behalf of Disaster Monitoring Constellation (DMC)	DMC Constellation

Charter interventions have supported activities in 107 interventions since November 2000, covering emergencies such as floods, fires, landslides, typhoons, volcanic eruptions, oil spills, tsunamis, hurricanes, earthquakes and civil accidents. In December 2004, over 200 sensor images were processed and distributed through the Charter in support of relief efforts and disaster management, following an earthquake and tsunami in the Indian

Ocean. In such circumstances the Charter allows partial relaxation of normal data policies for the purpose of protecting human welfare. For example, derivative data products processed through Charter activations can be shared without restriction. Although Charter activation involves unusual and extensive data distribution, the lost opportunities of sale may be insignificant because applications served are non-market in nature. Humanitarian consumer-groups are often excluded from the data market due to funding and budgetary constraints (Jackson et al. 1996) as well as significant knowledge gaps and technical shortcomings (Bessis et al. 2003, Spackman 2006).

The Charter allows commercial satellites with state-of-the-art technical capabilities to be employed in situations where markets and revenue-streams could not justify their deployment. Although the charter is categorised as an overall Club Good, this particular element of ICSMD has much in common with Orphan Drugs Scenario provision. Cynical observers note that extensive use of a commercial sensor for disaster management may provide exposure and publicity that bestow strategic benefits on the operating company in terms of developing market position or share.

As with Google Earth, ICSMD image-map products may be symbolic: they are commonly distributed as high-resolution JPEG images, shown Figure 4.5. No further analysis can be conducted despite the provision of metadata such as sensor position(s), date(s) of acquisition, processing agency and processing methodology. The decision to distribute data as downloadable map-sheets maximises accessibility and reduces technical overheads for field-based aid agencies and other humanitarian relief institutions. For the purposes of assessing excludability and rivalry in consumption, two ICSMD user-groups can be defined: those who are authorised to activate the charter, and those making use of data provided through the Internet.

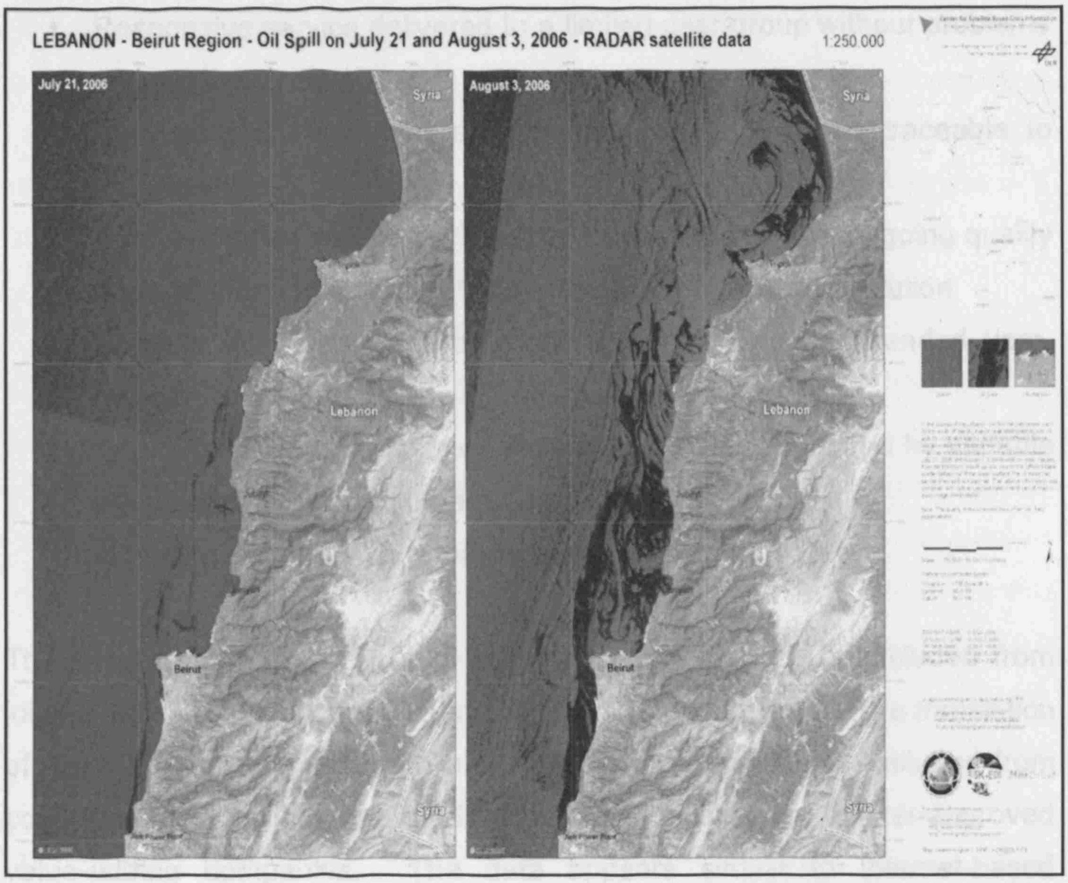

Figure 4.5 Image of an oil spillage near the Lebanese coast, August 2006. The product was prepared as part of an ICSMD activation, using ASAR, ETM+ and SRTM data (© ICSMD 2006)

To request data through ICSMD, users register and provide evidence of aid, civil defence or emergency remit. Following registration, authorised users are provided with contact details for a continuously-monitored charter activation centre. Non-members cannot request data. Once an activation has been approved, agencies are appointed to acquire and process timely and relevant data which is subsequently made available to all charter members and the general public. Restricted entitlement to charter activation is a club-based exclusion device – although membership is free of charge only certain personnel may join; a type of qualification excludability. Use of a closely monitored 'allow list' has the following benefits in Club Good management.

- Responsive service delivered to a limited user-group without problems of crowding or rivalry
- Monitoring ensures that service abuse is limited and traceable to individuals
- The user-group can be periodically surveyed to ensure ongoing quality of service and to incorporate user feedback in service evolution
- Benefits (free data) can be more tightly focused on intended user-groups
- Activations can be evaluated individually. This is required by variable intervention types and data requirements
- Non-cost membership removes price-based excludability

The second ICSMD user-group is composed of individuals excluded from joining the club of authorised users. This group cannot control the translation of Earth Observation data into useful information, but is not excluded from consuming information generated and released by selected charter-approved value-adding companies. The data appears similar to Internet-based Information Goods of other kinds, such as share-prices or online news, with two key exceptions. Love (1994) characterises Merit Goods as having greater value when shared widely, as is the case for ICSMD products. They are designed to be widely distributed and used by as many interested groups as possible for reduction of human suffering. The other component of Merit Goods is their costly generation. Acquiring and processing satellite data requires expertise for which value-adding companies are compensated with ICSMD operating budgets (Stallkamp 2006, Bessis et al. 2003). ICSMD data, once made available on the Internet, can be considered a hybrid Merit Good.

For authorised users the charter provides access to a regulated, non-cost, allow-list club. Other clubs exist with similar roles to ICSMD, introducing opportunity for consumer-choice and substitutes. Respond and UNOSAT are initiatives which supply geoinformation for developmental or post-disaster support, and Reuters AlertNet and ITC-Disasters Information and Analysis Group (DIAG) provide relevant up-to-date information to the aid community, including satellite data. Clubs can effectively manage information services in the non-market sector; Smith (2006) comments that inter-club competition, even in non-market environments, stimulates efficiency and may improve overall level of service. ICSMD and similar clubs are illustrated Figure 4.3, label 8.

4.3.1.9. ***Very High Resolution Sensors***

Very High Resolution satellite remote sensing, at ground pixel resolution of less than 4 metres, migrated from the military to the commercial domain when Russian KVR-1000 satellite images became publicly available in 1992 (Bonazountas 2002). Classified military sensors had operated at this resolution for more than thirty years (Steinberg 1996 in Bjorgo 1999) but the end of the Cold War led to the Russian decision to develop markets for such data. Following the first data sales by marketing and distribution companies Sovinformsputnik and Priroda in the early 1990s, the Clinton administration passed the Land Remote Sensing Policy Act (1992), allowing commercial operators to operate space-borne sensors with spatial resolution of 1 metre or less (Tripp 1995, Gupta 1995, Bjorgo 1999). The legislation aimed to "support and enhance US industrial competitiveness in the field of remote sensing space capabilities, while at the same time protecting US national security and foreign policy interests" (Bonazountas 2002).

The first commercially developed very high resolution satellite was EarlyBird, launched in 1997, but the sensor failed to reach stable orbit. Three very high resolution satellites are currently operational; Ikonos-2 (1999), Quickbird (2001) and OrbView-3 (2003). The Israeli satellite EROS-A1 is capable of sensing at sub-1 metre ground pixel resolution, but data is not yet commercially available.

Excepting exclusive government use for purposes of national security (under the 1992 US Act), data policy in very high resolution remote sensing aims for profit-maximisation and the establishment of market share in the commercial provision of a Private Good. Price-based exclusion is used, and in contrast to previous business models in Earth Observation such as SPOT and

Radarsat, suppliers set competitive market prices at levels that enable them to remain competitive and profitable and to recover fixed costs. A need has emerged to differentiate in an increasingly congested market, in terms of timely delivery, responsive tasking or image quality. For areas outside the continental USA, 2006 prices range from US \$35 per km^2 for 1 metre Ikonos panchromatic scenes to US \$48 per km^2 for similar data from Quickbird, although several distributors offer bulk discounts, home-territory discounts and reductions for flexible 'best-effort' tasking. In addition to tasked acquisitions, archive imagery (controlled by the same usage policies) can be purchased at reduced rates. For Quickbird, the guideline price for archive data is US \$18 per km^2 with a minimum order of $25km^2$. For many applications, data that may be many months old is adequate, and tasking is unnecessary. For some users the currency of data is a key element of value; in these circumstances Bonazountas (2002) comments that "an entire class of users, specifically academic researchers and developing nations, has encountered increasingly limited access to data from these systems, due to increased prices".

Without the support of initiatives such as Unosat and Respond, who distribute very high resolution data free-of-charge as map-sheets (shown Figure 4.3, label 9), the social-good utility of very high resolution satellite remote sensing could not be shown because data is priced outside the reach of humanitarian agencies, who are the biggest non-market consumers of geoinformation. For some information-types, value is not realised until the information is effectively used. As with ERS data policy before the 1994 price reduction, price-exclusion of Public Good activities such as pure science and humanitarian relief prohibits the demonstration of value that those activities could supply, which inhibits subsequent market development.

Commercial products are exclusive because of pricing and licensing; very high resolution satellite data is also extremely rivalrous in the same way as SPOT and Radarsat. To acquire data at very high resolution the satellite must be tasked. Additionally, sensor swath is typically narrow, which restricts useful 'incidental' data gathering. Satellite time is limited, and operators must balance the demands of many consumers (as with AVHRR). Very high resolution sensors operate in the optical spectrum, so multiple satellite-tasks may be required to acquire adequately cloud-free images. Consumers are rivals in the tasking of the sensor and in the subsequent processing and delivery of data to the degree that waiting lists determine the rapidity of data delivery more than orbital passes or environmental conditions. The majority of very high resolution data is provided entirely as a Private Good, shown Figure 4.3, label 9a, excludable on the basis of price and legally-binding licence agreements and rivalrous in terms of satellite tasking. Some very high resolution data is provided by value-adding companies in the context of wider project-reporting, and a small amount is provided free of charge to club-members for humanitarian use (discussed in section 4.4.3.1).

4.3.2. **Summary**

Revisiting Figure 4.3 (reprinted Figure 4.6) it is clear that duplicable digital data is fundamentally non-rivalrous - this quality is embedded within the data, and any rivalry is superimposed by policy or procedure. Because of this, most data sources are grouped to the left-hand origin of the rivalry axis. Three groupings are evident among the Earth observation data providers examined; Public and Merit Goods, Club Goods and Private Goods.

The first group is defined by relatively open-access data policies set down by US Federal authorities and the World Meteorological Office. Due to the absence of rivalrous tasking, data from weather satellites (1) and Landsat (2) appear closest to Public Good in status. NOAA AVHRR (3) would be categorised as a Public Good, except for rivalrous HRPT / LAC coverage. Some excludability in terms of tasking also alters the positioning of the SPOT sensors (5a) and Envisat ASAR (4a). For concessionary purchases by recognised scientific users, data can be provided under Merit Good provisions.

In the second group, non-cost Club Good provision can be employed as an exclusion device for a variety of reasons discussed in section 4.2.7.2. Data remains non-rivalrous because it is digital, and excludability is achieved by imposing conditional club membership. Club Good schemes are implemented by Google Earth (7) for the purpose of policy compliance, by the International Charter for Space and Major Disasters (8) for responsiveness and monitoring, and by VHR optical providers (9) for social benefit and strategic reasons.

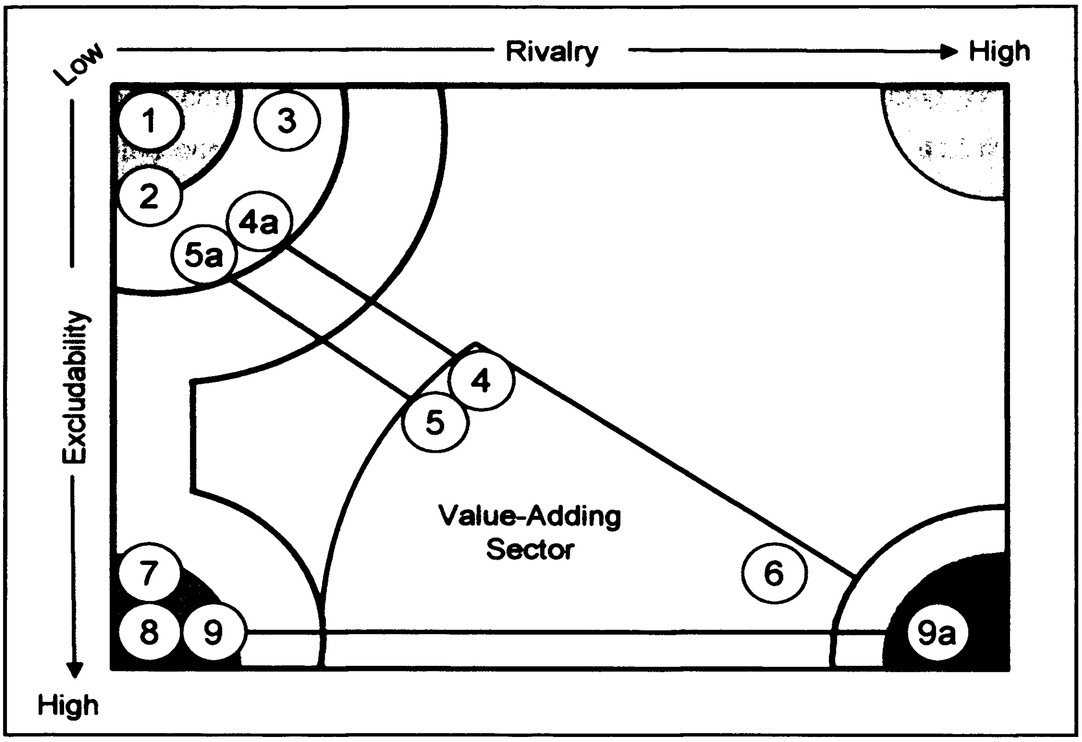

Figure 4.6 Reprint of Figure 4.3 showing the landscape of Goods, populated by Earth observation missions and data providers. Labels are identified section 4.3.2 and Table 4.4.

The third group includes all supply that is exposed to market forces via distributors and commercial pricing, where data is traded as a Private Good commodity. All non-concessionary SPOT (5) and Envisat ASAR (4) data falls in this region. The group shows that policy decisions in the form of collection and processing schemes can superimpose rivalry to varying degrees, and that investment in technical infrastructure or intellectual capital can be reimbursed using price as a cost-based excludability mechanism. This is exemplified by Radarsat (6) and VHR optical systems (9a).

4.4. Temporal Variability in Publicness

Figure 4.6 populates a public-private coordinate space with points illustrating key characteristics of modern Earth Observation sensors. This 'map of publicness' could be used to define appropriate management strategy and data policy, but the figure cannot accurately capture temporal variability in publicness, an important dynamic component of Earth Observation value. Although some publicness of value is embedded within Earth Observation data, some components reflect values that can change according to world events, the currency of information, technological developments and market requirements. Figures 4.7 and 4.8 explore typical changes in Earth Observation data categorisation following a variety of events and market situations.

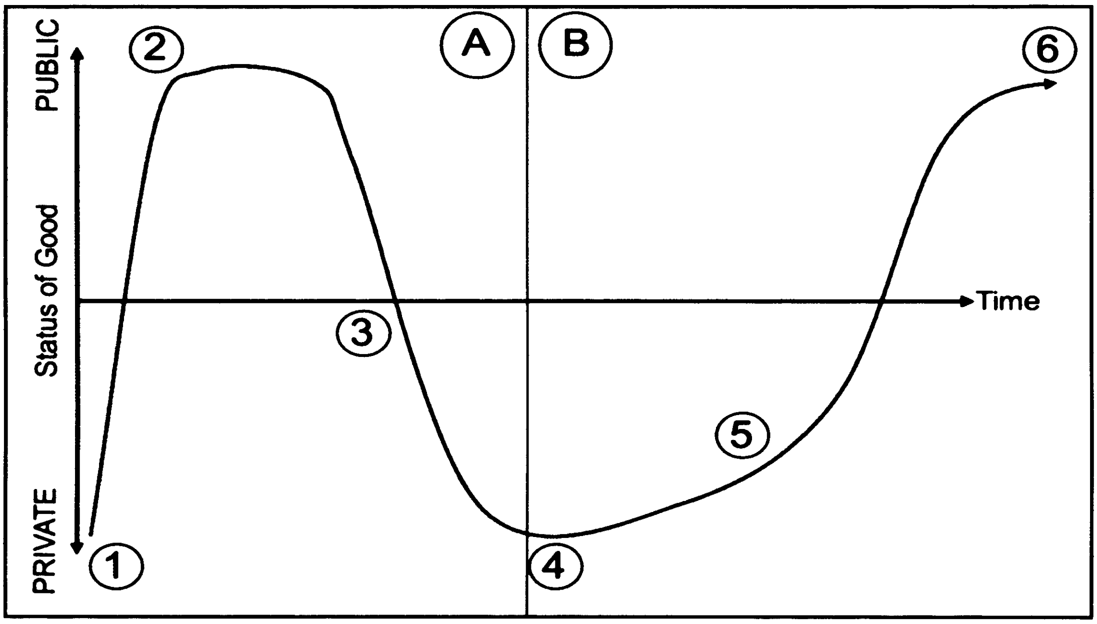

Figure 4.7 Alteration and development of Public / Private character of Earth Observation Goods over time. Section 4.4.1 describes this diagram.

4.4.1. Marketed Data

Figure 4.7, section B (to the right of the diagram) represents a typical life-cycle for marketed data. Position 4 represents the status of newly-acquired data of the type that has high market value. Commercial and value-adding users purchase data from distributors in positions 4 and 5, when very strong excludability and rivalry maintain high prices. As the data currency declines, utility shifts from profitable market-leading activities to lower level uses such as change detection, modelling support or base-map generation. Lower currency and greater obsolescence mean that prices are typically lower. For market segments such as meteorology, oil slick detection or fire monitoring, the value of data falls very sharply after acquisition. Due to reduced willingness-to-pay among consumers and the existence of newer substitutes, it may no longer be financially viable to invest in marketing as the age of data increases, shown as position 6. Elements of bequest value and responsibility of stewardship suggest that data should be stored, but very few consumers express willingness-to-pay equivalent to market price. At this stage the value-type of data shifts into Public and Merit Good territory. Maintenance of records may become a centrally funded activity to prevent the destruction (or neglect) of data. Goods of this kind are unique and irreplaceable, so considerations of existence value and option value increase the willingness-to-pay of government to maintain archives. The migration of data to centrally-funded archives often coincides with the data being made available free of charge or for COFUR under incremental pricing.

4.4.2. Non-Market Considerations

Section A (to the left of the diagram) shows circumstances which apply when data can contribute to humanitarian emergency response. Administered as hybrid Public Good, Merit Good and Orphan Drug Scenario interventions, reduction in human suffering forces a transposition of relevant new data from position 1, where it is extremely marketable, to position 2, where distribution of the Good is in the public interest and no commercial exploitation is sought. The moral obligation to provide information which can save human life and improve emergency response has been formalised through Earth Observation programmes such as Unosat and Respond, which are discussed in more detail in Chapter 6. When it is established that lives are no longer in danger (normally when the official state of emergency ends) the role of Earth Observation data changes as users begin to express willingness-to-pay.

Products distributed during the early stages of emergency response may remain available under Merit Good or Orphan Drug Scenario provisions, but newly acquired data of the area have market value as tools for reconstruction, as data sources for governance, or as the source of competitive advantage for developers and private companies. Investment of intellectual capital by private-sector companies permits them to exercise property rights and implement exclusion devices (most typically prices) to reflect demand. In this way even data that resides in the public domain, such as Landsat archives, can be marketed as a Quasi-Private Good if processing has significantly altered its information content. Post-disaster locations undergo market recovery as the dominant Hybrid Goods of position 3 are replaced by value-added products supplied through markets in position 4.

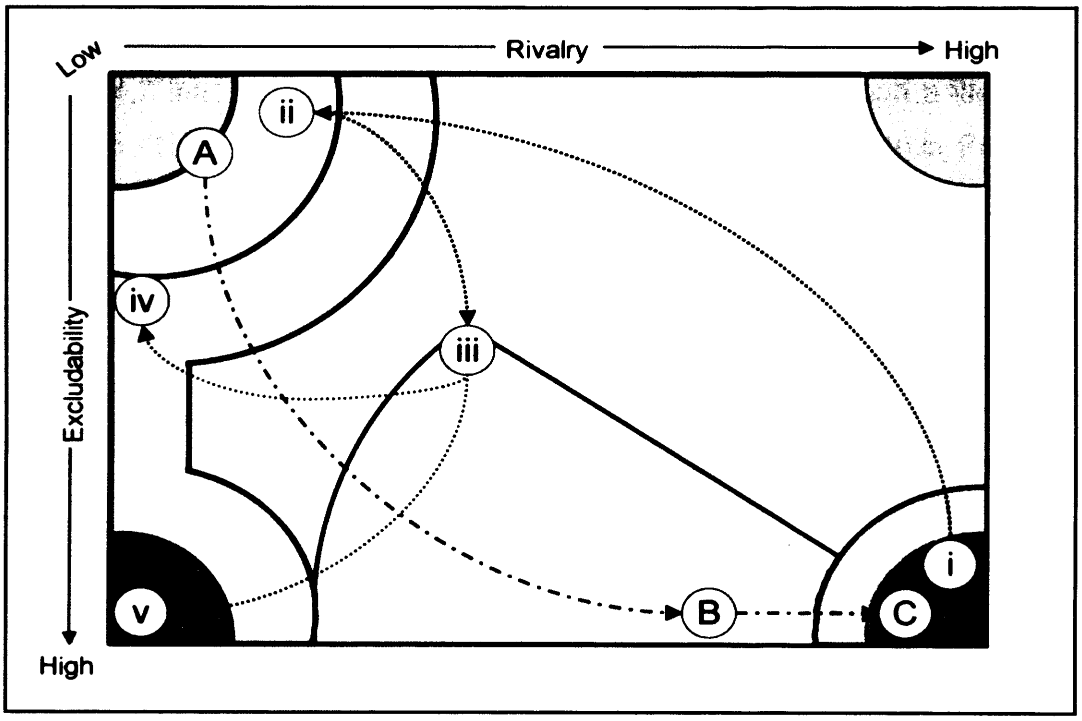

Figure 4.8 Changes in the Public-Private character of an Earth Observation Good in response to humanitarian emergency. Section 4.4.3 provides an analysis of this figure, and Table 4.6 provides a key.

Table 4.6 Key to Figure 4.8, summarising properties of Goods at marked locations

Label	Properties of the Good
i	Private Good; highly rivalrous and highly excludable
ii	Merit Good; provision by private sector, consumption is in public interest
iii	Hybrid Good; private sector data modification introduces property rights
iv	Information Good; largely non-rivalrous with variable excludability
v	Club Good; non rivalrous but exclusion strategies control consumption
A	Merit / Public Good; can be funded through taxation and provided to citizens
B	Quasi-Private Good; excludability & rivalry superimposed via property rights
C	Private Good; rivalrous and excludable, market provision

4.4.3. Examples of Temporal Variability

Figure 4.7 introduces concepts of dynamic 'publicness' through a life-cycle diagram. The extent to which a Good can be considered Private or Public is subject to alteration through data obsolescence, changes in world events and other factors. Referring to the public-private coordinate space first discussed in section 4.2.7, it is possible to record the route taken by data through the landscape of 'publicness'. Figure 4.8 includes two hypothetical scenarios; a Quickbird image depicting a natural hazard event which led to significant loss of life, and a Landsat image that covers the site of a proposed industrial development.

4.4.3.1. Very High Resolution Data for Public Good

Figure 4.8 label (i) represents the original market position of Quickbird data as a highly excludable and rivalrous resource, distributed under schemes of competitive market pricing. The occurrence of a natural hazard event changes the status of data because it provides an unrivalled synoptic view, which is advantageous for planning and executing post-disaster recovery efforts. Merit Good provision, illustrated by label (ii), is justified by moral obligations to provide data for humanitarian assistance without hindrance from market provision and licensing. If data is not provided free of charge by suppliers, public funding from the stricken country or from a contributing third party can be used to support purchases.

Several policy frameworks are in place within Earth Observation to integrate private-sector data providers and value-adding companies in humanitarian action, shown label (iii). Enabling mechanisms of this kind are discussed in section 6.2. Label (iv) and (v) illustrate destinations for processed data. Label (iv) shows the positioning of image-maps and other symbolic products (which can no longer be interrogated using image processing software) as Information Goods which approach Merit Good status. Single-layer images of this kind are commonly made freely available on the internet under schemes conceptually similar to Orphan Drug Scenarios. Data are considered Information Goods because digital resources are not rivalrous and excludability is variable. Non-rivalry occurs when infinite perfect duplicates can be produced and distributed with no reduction in the quality of the original. Variable exclusion can be introduced through data policy. Although some socio-cultural 'soft' excludability may occur (Kaul 2001), data from humanitarian interventions are not usually subject to distribution restrictions, and can be hosted and distributed freely through online distributors such as Respond, ReliefWeb, and Reuters AlertNet (discussed in more detail in section 6.2). Information Good data sources can approach Merit Good status when their wide application brings social benefits (Love 1994). Data which has retained integrity, and which can be used as the basis for more detailed analysis is more commonly subject to more stringent exclusion devices. Multi-dimensional files represent significant intellectual property and could form the basis for commercial exploitation if distribution channels were abused. To prevent such abuse, and to provide information about user-groups and consumption patterns, simple methods of non-cost exclusion such as passwords and 'allow lists' can be employed. As an example of an online service for the humanitarian aid community which has implemented this approach, Reuters AlertNet operates parallel distribution channels represented by labels (iv) and (v) for different categories of data.

4.4.3.2. ***Exploitation of Public Sector Data***

Label A represents the distribution of Landsat data as a hybrid Public / Merit Good by US federal agencies, under data policies that reflect public funding of sensor development, launch and operation, and which aim to stimulate growth in the value-adding sector (Love 1994, Thompson 2000). Data enhancement (label B, within the value-adding sector) enables the enforcement of property rights by those who have invested time, expertise and intellectual capital. These investments transform freely available data into commercially viable information. Commercial data processing superimposes rivalry and excludability on images; the rivalrous and excludable resources for sale in label C are time, expertise, and equipment. To use an example, a company may plan to build industrial units on a brown-field site, for which they require a geological assessment, land-cover mapping and an accurate estimation of distances to the nearest water supply, electricity substation, and major load-bearing carriageway. In competition with suppliers who do not use Earth Observation, a value-adding company submits a proposal which is accepted. The company does not pay for the Landsat scenes used to prepare the report, but the consultancy fee is defensible based on other investments.

4.5. Conclusions

Rigorous examination of value-types associated with Earth Observation had not been undertaken before this research. Components of value were poorly understood by consumers and suppliers within Earth Observation. Weighting non-market benefits and mapping public-private value types are novel approaches within Earth Observation, but similar problems of value-capture have been the subject of interest in environmental accounting and law, for example. Methodologies developed to capture complex value-types in other disciplines contribute to discussions of Earth Observation characteristics, and can enable the development of a logical and robust new model of value.

Examination of the public-private Good characteristics of Earth Observation data sets reveals complexity in the form of previously unidentified temporally variable hybrid value-types. If components of total value are known, Goods can be more effectively managed through appropriate mechanisms of marketing, pricing, supply and distribution. In Earth Observation, the rather simplistic valuation schemes that have become the industry standard do not capture value with sufficient precision or in enough depth to support informed management, and they have led to consistent undervaluation of the sector, alongside conservative estimates of socio-cultural contributions. Industry development has been inhibited by lack of information and inappropriate management choices, although progress has been made in some areas: Envisat data policy and several programmes of humanitarian data provision implicitly acknowledge Public Good and Merit Good applications of Earth Observation data.

The broad range of value characteristics identified in Section 4.3 indicates that flexibility and adaptability are key requirements for successful data management and distribution schemes. Results suggest that 'one size fits all' policies, and those which solely aim to develop commercial markets do not serve the Earth Observation industry well. Technical progress has brought rapid changes in capability and capacity, which are not reflected in current licensing and distribution technologies. New policies (which are urgently required) should take advantage of innovative distribution conduits, encryption technologies and access-control measures that are more scalable and customisable than ever before.

Chapter 5 THE VALUE OF EARTH OBSERVATION DATA IN FORESTRY

5.1 *Introduction*

5.1.1 Chapter Aims

> *Mieux vaut prévoir sans certitude que de ne pas prévoir de tout* – It is better to predict without certainty than not to predict at all (Henri Poincaré 1902).

This chapter evaluates the contribution to Earth Observation data value that can be attributed to forestry data usage. The chapter introduces and develops a robust and applicable model of value which builds on discussions of publicness and provides a framework for assessing in a repeatable way the value of Earth Observation data. The Public Good characteristics of Earth Observation were evaluated in the last chapter, where discussions centred upon the ways in which data value types are embedded or superimposed. This chapter evaluates value within a single application: forestry. The case study aims to characterise industry-specific value structures by examining the extent and contribution of current data exploitation within the UK and northern Europe. Foresters were asked to complete a questionnaire, which was supplemented by follow-up interviews and site visits.

The first section of this chapter contextualises the research by discussing monitoring requirements in forestry and introducing themes of legislative change that may affect data collection regimes over the next decade. The second section presents the definition, global extent and significance of forest cover, and discusses historic and future interactions with humankind. Modern operational forestry activities of planning, management, survey and harvesting are introduced in the third section. The fourth section concentrates on the information requirements of forest managers and evaluates the extent to which these requirements can be fulfilled using Earth

Observation data sources. A brief review of forest survey costs on a per-hectare and global scale is provided. The fifth section introduces the aims and methodology of the forestry survey, undertaken to gather new information about interactions between foresters and Earth Observation data sources. In the sixth section, responses to survey questions are evaluated and related to issues identified earlier in the chapter. The seventh section introduces two brief illustrative examples of forest mapping and management using Earth observation, located in Galloway, south-eastern Scotland and in the Finnish forest reserve of Kivalo. Forest managers from the areas have viewed and validated results. Finally, relationships between foresters and Earth Observation data are assessed, using information from all of the preceding sections. Building on this discussion, a model of value is presented which allows non-technical foresters to more effectively and incisively evaluate potential contributions that can be made by satellite data. A generalised model is also presented for deployment and testing in the humanitarian aid sector.

Foresters in many regions of the world have been exposed to Earth Observation data for many years, and the key capabilities of satellite remote sensing appear to offer solutions to many operational problems in forestry, typically providing data at lower cost per sampled area than any other approach (Suarez 2002, Reese et al. 2003), and providing more frequent revisits than are possible with alternate approaches (Schuck et al. 2003). Achieving timely coverage of spatially extensive areas which have limited or hazardous human access is problematic and has traditionally involved extrapolation from limited surveying. Foresters require information on the extent, health, and distribution of trees, the circulation of pathogens and the quality of soil and drainage.

In addition to the long-standing requirements of traditional forestry, two other drivers lead to an increased requirement for monitoring of forested land surface. The first is an attitudinal change among the public, reflected in modern forest management strategy, which redefines forest areas as significant repositories of biodiversity and areas of high environmental value with important recreational and social functions. The UK Forestry Commission considers the preservation and enhancement of recreational and environmental value to be a primary objective in some sites; in some Scottish plantations "timber is a secondary product" (Jones et al. 2003, Forestry Commission 2004). Management of forests in this way is increasingly mainstream. Slee (2004) advocates responsible stewardship of "valuable natural capital", an assertion echoed by the Food and Agriculture Organisation (2005), who find that since 1990 "the focus of forest management in Europe clearly shifted away from productive functions towards conservation of biological diversity, protection and multiple uses". The second driver is a growing legislative requirement to produce forest products such as timber or fuel wood in a sustainable way following agreements such as the Kyoto Protocol, which identified plantation forests as a viable carbon sink and provided the framework for the development of carbon trade agreements (Pearce 1995, Gilbert 2003, European Union Greenhouse Gas Emission Trading Scheme (EU ETS) 2005, International Emissions Trading Association 2006). With the aim of creating sustainability, effective regional management relies on the acquisition of up-to-date and accurate forest parameters (Cabinet Office 2001, de Wasseige and Defourney 2003, Leyk, Koehl and von Poncet 2002). National policy objectives often follow international requirements, and more detailed management of national forest resources facilitates the development of national carbon accounts and supports national measurement of land cover and environmental change.

Under the next generation of environmental legislation, forest areas which are not profit-making and of little economic value will for the first time be subject to detailed management plans (Häusler 2003), inspiring a need to develop cost effective monitoring regimes. Howard (1991) discusses changing obligations and data requirements of landscape management and concludes that "remote sensing can be expected to be used to collect urgently needed data, especially as related to ... evaluating the productivity of the land and providing information not only for inventory but also for direct inputs into forest management and strategic planning".

5.1.2 Case Study Design

To clarify operational problems in forestry, which are inconsistently represented in peer-reviewed literature, it is important to involve professionals from within the sector (Global Forest Resources Assessment 2000, Food and Agriculture Organisation 2000). The case study is conducted as an inclusive consultation incorporating a questionnaire, interviews and site visits. It was vital to address groups of users who have been under-represented in past research through incomplete or inefficient research design. Critical path work package analysis, illustrated in Figure 5.1, shows the two-step research strategy which incorporates respondent feedback in questionnaire administration.

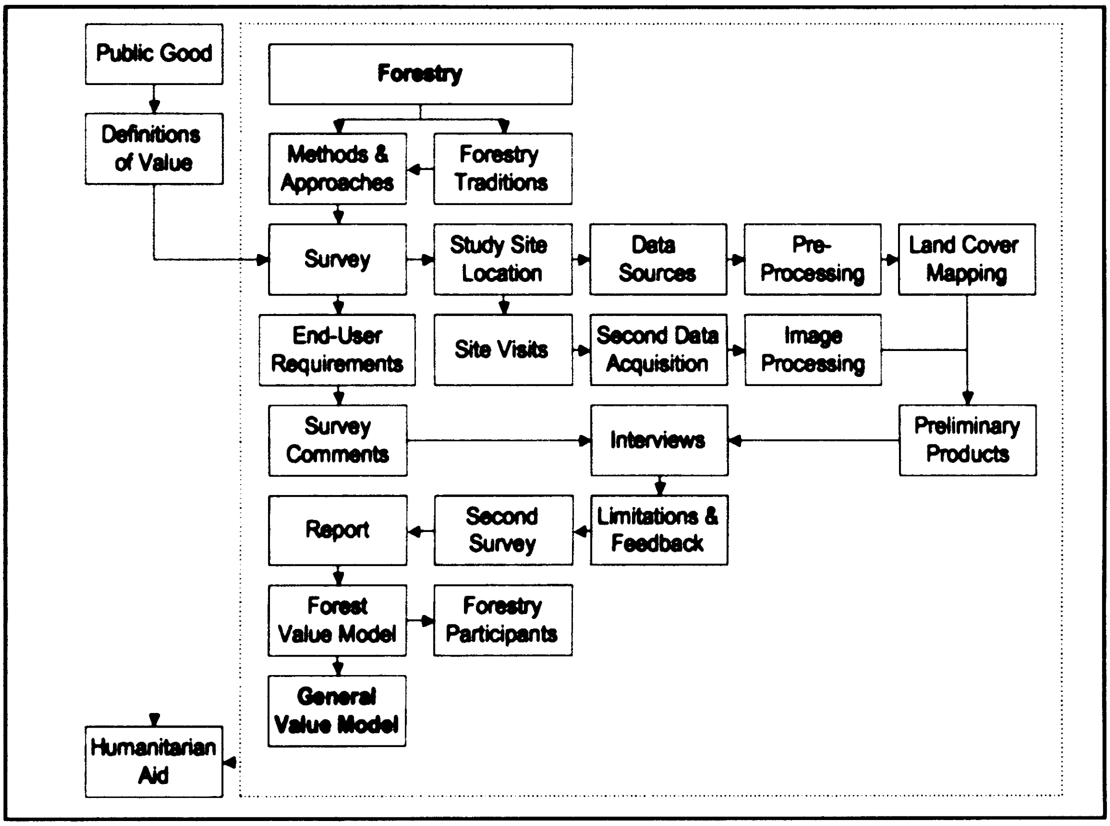

Figure 5.1 Critical path diagram to show structure of forestry research design.

Uptake and implementation of remotely-sensed approaches has been limited within forestry, except in nations where forest comprises a significant ground cover, such as Scandinavia and Canada. In academia, forest applications have remained a source of research interest for more than 25 years (Leckie 1990, Wagner et al. 2003, Gerard 2003, Leckie et al. 2003, Remmel et al. 2004, Hale, Levy and Gardner 2004). While it is widely acknowledged that "traditional forest inventories have been based on cost-intensive and time-consuming field inventories" (Leyk, Koehl and von Poncet 2002) and a stream of proposals for remote sensing-based operational forest products have been developed, very few processing methodologies and data sources are in regular and widespread use. This clearly signals the existence of impeding factors to the objective evaluation of Earth Observation technology in forestry. Over fifteen years ago Aronoff (1989) investigated relationships between foresters and remote sensing scientists, stating that "foresters have no experience with remote sensing and therefore cannot evaluate its potential".

To the present day the remote sensing community has been unresponsive to the needs of foresters and has not provided useful products (Donoghue 2005, personal communication). Foresters have still not found an acceptable conduit to express their needs to the research community. The so-called 'knowledge gap' has widened and impedes communication between academic researchers and foresters. Alongside the gulf between academic and operational interests in forestry, value-adding companies and data suppliers have not been successful in developing a user-base for their products. Without acceptable and predictable revenue streams, the software, data and training suppliers have concentrated market-development activities elsewhere (primarily in the fields of oil and gas and civil engineering).

A questionnaire provides a means of approaching individuals and organisations to characterise operational data requirements and the relationship between users, suppliers and researchers. Consultation of this kind provides an opportunity to gather and respond to their comments and experiences, and introduces an important element of first-hand experience to the research. Impressions and statements from survey respondents informed the development of the value model presented as a chapter outcome.

5.2 *Forest Landscapes*

5.2.1 **Definitions**

The modern definition of forestry was established more than 60 years ago at the 1944 Bretton Wood conference of the Food and Agriculture Organisation (FAO). The conference agreed that forest comprises "all lands bearing a vegetation association dominated by trees of any size, exploited or not, capable of producing wood or other products, of exerting an influence on climate or on the water regime or providing shelter for livestock or wildlife" (Loetsch and Haller 1964, cited by Howard 1991).

Rietbergen (2001) warns against the assumption that any significant area of unmodified natural forest remains in Europe. Even woodland which appears wild and unmanaged may have a long history of human intervention. "Whatever the intentions of the [historical] users and managers, biologists are increasingly aware that many species depend on continued human disturbance to thrive." Rietbergen continues: "a very common threat to biodiversity in Western Europe is the discontinuation of ancient forest management practices." It has been difficult or impossible to quantify accurately the changing management of European forests because many regimes of human intervention occur at scales that are not detectable using national survey approaches.

In other regions, so-called primary forest cover identifies ecosystems and processes largely unaffected by human-impact (Figure 5.2). The Food and Agriculture Organisation (2005) states that primary forest area is diminishing by up to six million hectares per year, shown Figure 5.3. This contention is supported by Jonathan Lash of the World Resources Institute (WRI), who comments "as we examined what we thought were vast, untouched stretches of intact forest in the world [shown Figure 5.2], we came to the conclusion that they are fast becoming a myth" (BBC 2002). The reasons for these changes are complex and include deforestation for timber production, fuel-wood collection and other anthropogenic modifications. As a result of these changes, many areas degrade from primary to modified natural forest cover.

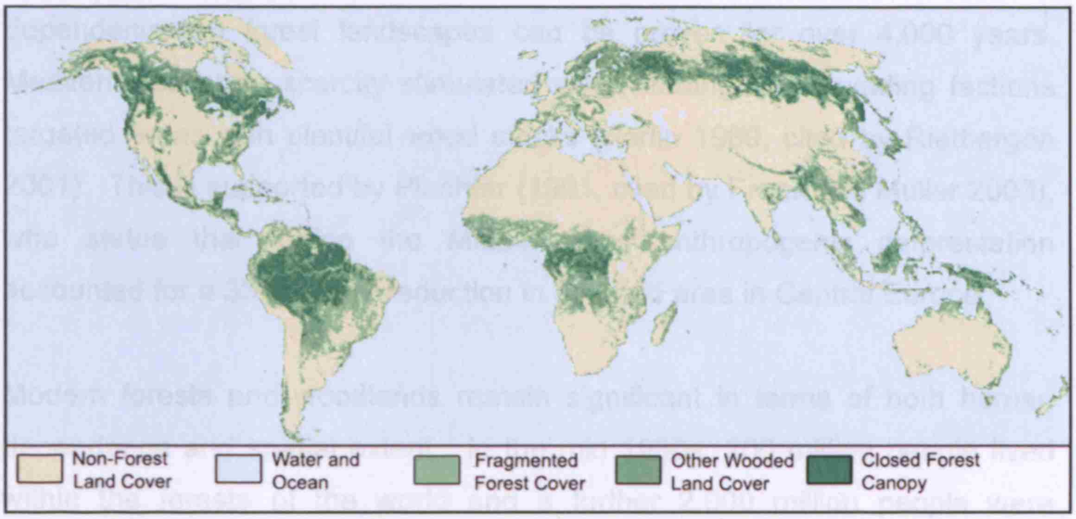

Figure 5.2 Earth observation-derived global map of forest cover, created using the AVHRR sensor as part of the Food and Agriculture Organisation Global Forest Resource Assessment (USGS Global Land Cover Characteristics Database 2005).

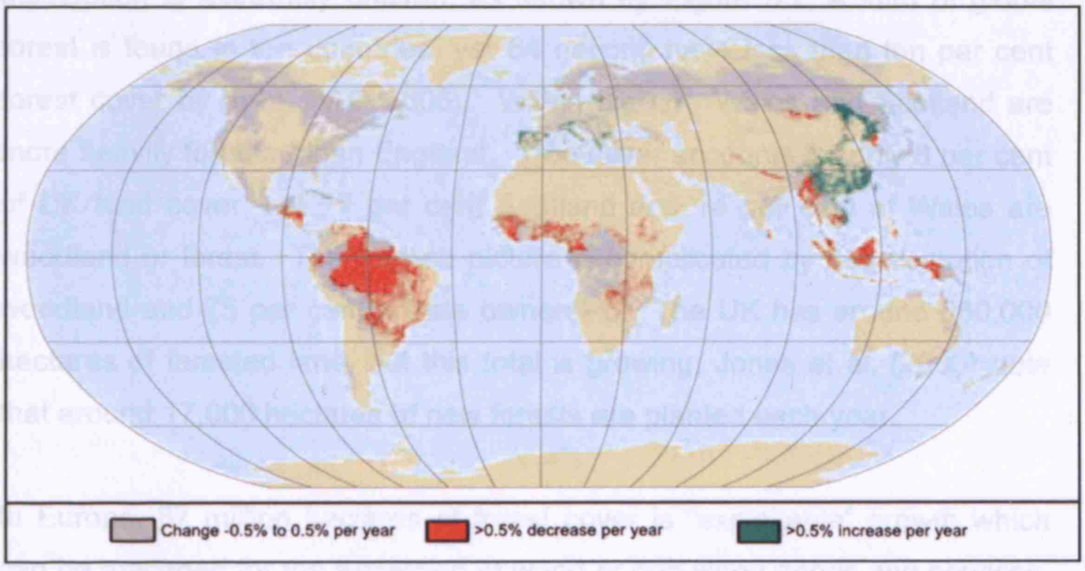

Figure 5.3 Areas of diminishing primary forest cover in 2005, identified by the Food and Agriculture Organisation (adapted from Forest Resource Assessment 2005).

5.2.2 The Importance of Forestry

Forest has been exploited by mankind for thousands of years as a source of wood for energy production, industry and building materials, and as a habitat for sheltering livestock and hunting wildlife (FAO 2005). In Europe, dependence on forest landscapes can be proven for over 4,000 years. Mediterranean tree scarcity stimulated wood trading, and invading factions targeted areas with plentiful wood stocks (Perlin 1989, cited by Rietbergen 2001). This is supported by Plachter (1991, cited by Frank and Muller 2003), who states that during the Middle Ages anthropogenic deforestation accounted for a 33 per cent reduction in forested area in Central Europe.

Modern forests and woodlands remain significant in terms of both human dependence and spatial extent. In the mid 1980s, 200 million people lived within the forests of the world and a further 2,000 million people were dependent upon forests for domestic energy (Flores-Rodas 1985, cited by Howard 1991). The United Nations Food and Agriculture Organisation estimate that 10 million people are employed in forest conservation and management roles (2005) and that 25-27 per cent of the Earth's surface is covered by forest (UNFAO 2000, 2005, Schuck et al. 2003). Global forest distribution is extremely uneven, as shown by Figure 5.2; a third of global forest is found in ten countries, yet 64 nations have less than ten per cent forest cover by area (FAO 2005). Within the UK, Wales and Scotland are more heavily forested than England. Tree cover accounts for only 8 per cent of UK land cover, but 17 per cent Scotland and 14 per cent of Wales are woodland or forest. The English picture is complicated by fragmentation of woodland and 75 per cent private ownership. The UK has around 860,000 hectares of forested land, but this total is growing; Jones et al. (2003) note that around 17,000 hectares of new forests are planted each year.

In Europe, 87 million hectares of forest cover is "exploitable" growth which can be managed for the extraction of wood or non-wood goods and services. Eurasian boreal environments account for 20 per cent of global forest cover and Canada contains a further 10 per cent (Remmel et al. 2004 and Gaveau et al. 2001). The Russian Federation including Siberia has the largest national forest area; 808 million hectares. In addition to major regional areas of forest cover, forest management issues are of greater importance in nations where it is a significant or dominant landscape type. Sweden, for example, is 65 per cent forest by area (Reese et al. 2002).

5.2.3 Significance

The perceived value of UK forest has changed in recent history. Following the 1973 oil crisis, Howard (1991) identifies an increase in forest value due to the elevated cost of crude oil and uncertainties about future supply security. Locally available and plentiful supplies of energy, such as fuel-wood in Europe, were re-evaluated and exploited. Additionally, the escalation of the Cold War and a new era of political uncertainty increased pressure on governments to develop and protect domestic energy resources, which led to the establishment of many European forest plantation areas.

Forest ecosystems provide goods and services to the human population locally and elsewhere. Global-impact Public Good services, as identified and discussed by Pearce (1993), include atmospheric carbon sequestration and sinking, water cycling and watershed management, soil generation and protection and the maintenance of biodiversity in niche habitats. More intangible services include provision of recreation, as discussed in detail by Jones et al. (2003), and the related phenomena of existence value and bequest value, applied to forests by virtue of their uniqueness and the absence of adequate substitutes. More direct forest goods include fuel-wood, construction materials, and non-wood forest products such as pulp and other raw materials.

Changing attitudes are reflected in management and design plans proposed by Forest Enterprise and the Forestry Commission for Kielder and Galloway forest districts (Donoghue 2004 personal communication, Forestry Commission 2004), which acknowledge that the role of forestry has fundamentally changed, and that the timber harvest is now a secondary product. Stakeholder interests and the development of the forest as a leisure resource and a site of scientific and natural value have become increasingly important to managers in the UK (Wilson 2004, personal communication, Watt 2004, personal communication).

5.3 Management and Research

5.3.1 **Forest Management**

Traditional forestry survey approaches are well-established but were not developed to meet requirements of regional, national or global inventory. Traditional approaches such as the "hip chain and compass" method focus on timely, sustainable and cost-effective provision of a range of good-quality timber through *in situ* measurement regimes (Australian Bush Workbook 2004). Forest management strategies aim to measure, maintain and increase productivity towards the final objective of efficient harvest. In this landscape remote sensing has not been of interest to commercial foresters. The Indian GIS Development Agency, for example, states that "the use of sophisticated survey equipment ... has yet to dawn in this sector". They suggest that "in the present scenario, GPS appears to be a viable alternative [to the chain and compass] for accurate forest traverses" (2004).

Following an investigation by Aronoff (1989), the following operational weaknesses were identified in dominant remote sensing technologies for the purposes of forestry. Although technical progress and the commencement of UK development and integration programmes such as British National Space Centre GIFTSS and CPP (Government Information from the Space Sector and Customer Partnership Programs) appear to have invalidated some arguments, they are still cited by key authors and forestry managers (Woodhouse 2004, personal communication), which indicates their continuing influence.

- Insufficient spatial resolution
- Insufficient accuracy
- Excessive cost - "Earth Observation data is seen as a real money-pit" states Watt (2004, personal communication)
- Satellite data "are experimental"

- Satellite data are too complicated
- Insufficient coverage

Institutional inertia and historic 'overselling' of Earth Observation causes reluctance among forestry professionals to deviate from long-established and approved forest inventory techniques. The impact of the academic research community has been less dramatic than was expected, due in part to the breadth of the 'knowledge gap', but also due to the largely abstract nature of some scientific research; standardised and genuinely useful applications are rarely suggested. In some ways, the tools have been developed, but the instructions are not included.

The distant relationship between remote sensing scientists and foresters is also obviated by classification procedures. Due to differing provenance of forestry and remotely sensed classification systems, Koch (1996) discovers that "terrestrial classes cannot be directly converted into remote sensing classes" leading to problems of data migration and compatibility, a finding also noted by Remmel et al. (2004).

5.3.2 **Field Operations**

In the UK all major Forest Parks administered by the Forestry Commission have regional managers responsible for planning, harvesting and recreation. Figure 5.4 shows the national distribution of Forestry Commission sites. Even in areas without large tourist numbers a sustainable forest management scheme has been increasingly implemented with a lower emphasis on harvesting and marketing wood products. Community forestry provides an accessible local resource for residents, which is intensively managed and planned.

Figure 5.4 Forestry Commission woodland distribution and access in England, Scotland and Wales (adapted from FC National Inventory of Woodland and Trees 2003 and Jones et al. 2003).

5.3.2.1. **Planning**

For new plantations foresters must decide on species mixture, tree spacing, planting scheme and access control. Although the species in common use in UK forestry are robust and mainly comprise fast-growing conifers such as Sitka Spruce, local conditions control vigour at stand and compartment level. Wilson (2004) comments that "Scotland can be considered a single catchment for the purposes of modelling, but the silviculturalist knows that soil type and drainage dynamic is hillside-specific". Foresters use soil mapping, drainage surveys and site visits to assess suitability, and research has identified complex indicators of within-stand variation and selective establishment (Nanos et al. 2004). Staff at Forest Research, the scientific and development division of the UK Forestry Commission, assess the relative success of tree species combinations and the potential for sub-canopy soil regeneration strategies as a viable alternative to traditional cycles of clear-felling and replanting (Wilson 2004, personal communication, Hale et al. 2003). Just as in precision agriculture, efficient data collection and site-specific measurements contribute to forest planning, a discipline where "models are increasingly used to assist decision-making ... [and] to address complex forest management issues" (US Board of Agriculture 1997, Hale et al. 2003).

5.3.2.2. **Management**

For newly-established stands up to 5 years old, forest managers check that saplings have established correctly and that planting strategy was appropriate. Intensive debate has centred on the planting techniques which include ploughing-in, dolloping and bedding, as illustrated Figure 5.5 (Löf et al. 2006). The methods have differing cost implications and it seems that certain techniques are more successful for some species (Wilson 2004, personal communication), but appropriate data is scarce. By combining digital compartment mapping (as shown Figure 5.11) with satellite data it is possible to gauge the relative effectiveness of management techniques under site-specific conditions in order to make valid recommendations regarding planting approaches.

It is possible to identify crucial periods in the growth of stands using time-series analysis of satellite data in association with change mapping. Wind-throw is a typical establishment problem, when fast-growing young trees with immature root systems are blown over. Disease and infestation or infection of tree stands has critical implications for the timber crop value because pathogens can reduce wood density and lead to double crowns, which are not as saleable. The emergence of tree growth problems and the development of growth problems can be mapped using remote sensing approaches. Active airborne and space-borne sensors can provide canopy height data with varying degrees of success (Donoghue 2004, Watt 2004, personal communication).

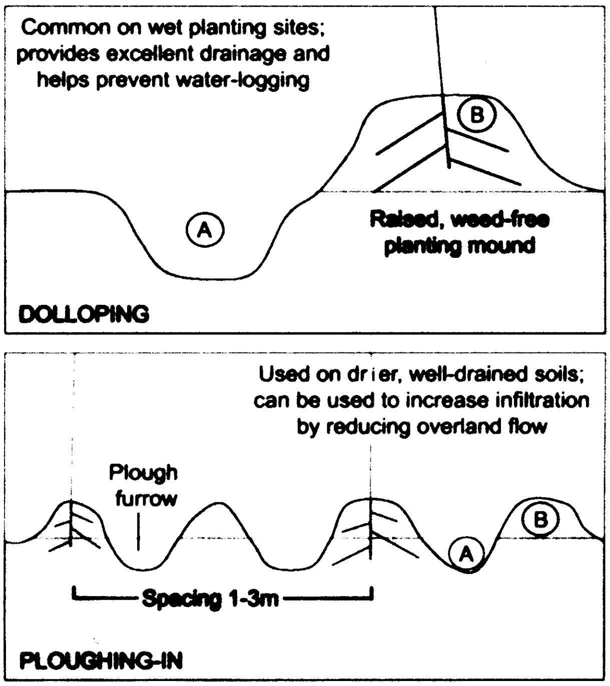

Figure 5.5 Planting strategies used by Forestry Commission in the UK. Dolloping (upper sketch) employs earth-moving equipment to create hollows (A) and planting mounds (B). Disruption of the ground facilitates sapling drainage and weakens the root systems of weed species. Dolloping increases risk of wind-throw on some soil types (Wilson 2004,

personal communication). Ploughing-in (lower sketch) can be used to reduce soil loss through overland flow, rilling and gullying on slopes. Saplings are planted on ridges, and furrows assist drainage (adapted from Lőf et al. 2006).

The pursuit of tree height derivation is a rapidly developing area of research and an important measure in the first years of tree growth (Watt 2004 personal communication, Neeff et al. 2003). Although some problems are easy to see on the ground, mapping discrete phenomena such as airborne parasite infections or within-stand wind-throw can be extremely challenging, especially when access is limited by dense planting, uneven ground and other common factors.

The requirement to monitor new plantations (illustrated by Figure 5.6) to comply with terms and conditions is a common stipulation of planting grants, which provide revenue for foresters in the UK. The grants typically confer a responsibility to check for the healthy initial establishment of the crop, and specify planting density and a maintenance period (2,250 trees per hectare and ten years in the case of the UK Woodland Grant Scheme). Faced with this management responsibility, Earth Observation approaches provide a cost-effective tool for foresters to check crops and collate geospatial statistics for reporting to the grant issuers (Kleinn 2003, Tomppo and Czaplewski 2003, Donoghue et al. 2004). Although optical satellite data has shown only limited potential for crown density estimation, mean tree height is accessible to an acceptable degree of accuracy (Donoghue et al. 2004). Height estimations for some species, such as Sitka Spruce, are strongly correlated with volume measurements (Philip 1998, cited by Donoghue and Watt 2006), indicating that optical sensors can be a useful tool for yield estimation in stands where canopy closure is not achieved.

Figure 5.6 New plantation, Galloway Forest Park (2004), showing Sitka Spruce trees. This stand is 7 years old. The picture illustrates planting density and problems of access due to dense vegetation and uneven ground surface.

Alongside ongoing management and inventory, *a priori* knowledge of the location and extent of developing problems allows effective implementation of remedial action for the developing crop and the effective deployment of staff and resources. These activities continue for more mature stands of trees aged 30-50 years, where trees are very fast-growing and can be densely planted, shown on Figure 5.7. Access to many locations is challenging and the ability to apply local solutions such as pesticide, fertiliser, drainage or thinning protects the standing crop.

Figure 5.7 Lodgepole Pine and Sitka Spruce compartment, Galloway Forest Park (2004), illustrating 1 metre tree spacing and mixed-species planting strategy. Access for monitoring and survey can be restricted by high-density planting of this kind.

5.3.2.3. Survey

Forest surveys conducted outside the influence of tax calculations, national inventories and top-level legislative requirements are primarily aimed at estimating yield. In the UK, tree yield class has been estimated since the 1920s with models parameterised using around 60 Forestry Commission field plots, from which empirical tree growth data is collected. The models accurately forecast yield class development for those sites, but inadequately represent the influences of site-specific factors such as substrate quality, local climate and atmospheric conditions. Some yield tables currently in use date from the 1960s, when a national wood surplus led to insufficient model validation and large error margins. Wilson (2004) states that the yield tables "are really very rough – they're just about good enough to attract sawmills and to keep stakeholders happy". Forest Research aim to replace outdated and simplistic models, declaring that "a different modelling approach is now required, not just for assessing the impact of climate change, but for many other reasons which include the prediction of canopy and forest structure, landscape visualisation for planning and predictions of the ecological and hydrological impacts of forest management" (Forest Research 2006)

The Forestry Commission estimate that harvesting surveys cost around £10 per hectare for the Galloway Forest Park, the largest single forest reserve in the UK (Wilson 2004, personal communication). Surveys of stocking density and tree establishment add around £15 per hectare, and soil type an additional £10 per hectare. The park is 90,000 hectares in area, of which approximately 16,000 hectares is surveyed per year, leading to stand coverage once every six years.

Alternative approaches to park surveying were investigated by Forestry Commission through invitations to tender in 2004. Typical advocates of aerial surveys quoted in the region of £25 per hectare: one satellite data supplier estimated £2,000 per year for coverage of the entire park at ground pixel resolution of around 15 metres. This data would be "easily good enough to check forest boundaries, felling and even conduct inventory studies" (Leckie 1990, Wilson 2004, personal communication), but the cost does not include training and hardware expenses. According to Donoghue and Watt (2006), "cost is an important consideration for the forest industry, given the declining price of softwood timber prices and the high cost of labour". Smith (2006, personal communication) notes that for Scottish sites "there has been, and is ongoing, an awful lot of work on the use of satellite data in forest survey and management ... [but] it isn't operational yet, and all costs of acquisition and use are not real operational costs, so they could be misleading".

5.3.2.4. Harvesting

Data requirements for forest harvesting are modest but improved geo-information yields efficiency gains and increases productivity. Stand harvesting plans are based on tree height and yield class, and all harvesting is undertaken in adherence to local strategic management plans, which aim to reduce impact on human and animal populations. Access planning and the safety of harvesting staff can be more effectively managed if drainage condition and slope can be included in planning stages, and Woodhouse (2004) states that "some of the most exciting developments regarding Earth Observation and timber cropping has been in the field of terrain modelling ... [the models] can be used to design an efficient and safe harvesting strategy – planning machine movements and staff placement is crucial". In addition to cost reduction, modelling harvesting strategy can also reduce risks to scientifically significant areas and archaeological sites, which may be near (or inside) forest boundaries.

Harvesting has been a lower priority in the UK because many Forestry Commission plantations have been removed from the harvested national inventory. This is due to the falling price of chip-wood and timber products and increased exploitation of forests by the public as a leisure resource. The value of forest as a public good is not underestimated by Forestry Commission but issues of tree health, access and facilities provision mean that the large Scottish sites in particular need a harvesting division.

Monitoring of forest harvest at regional level is challenging. Kittredge Jr et al. (2003) state that "although reliable information on forest conversion to other land covers is readily available and detectable through remote sensing, forest harvesting, the most important ongoing anthropogenic disturbance to the largest area of forested land, remains difficult to quantify". The authors note that accurate harvest figures contribute to more accurate carbon flux and biomass estimations.

5.3.3 Forest Information

The information needs of forestry are well-specified but the focus has not been on the acquisition of high-quality environmental data, but on developing tools to support reliable and cost-effective regional supply of good quality timber. Following this lead in the 1960s and 1970s, the Food and Agriculture Organisation relied almost entirely on field data for global forest inventory. Data collection was time-consuming, prohibitively expensive, and patchy in coverage. Following widespread use of Landsat MSS data in the late 1970s, Kleinn (2003) states that "satellite data and imagery then entered rapidly into

NFIs [national forest inventories], particularly in tropical countries, and the emphasis shifted from field observations to image interpretation". Kleinn goes on to discuss the merits of remote sensing as a basis for forest inventory and notes that the marketing and dissemination of image- and map-based products was probably simpler than for those based on "statistics and error tables" because of their ease of interpretation and intuitive nature.

Over the next twenty years, due to the unique viewpoint afforded by Earth Observation technology, remote sensing became a key information source for global forest monitoring as new sensors such as the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) became available (Kleinn 2003, FAO 2005). Regional level landscape management and policy implementation is complex and nationally variable, but there remains a general requirement for governments and decision-makers to evaluate effectively the economic and socio-environmental impact of all significant land cover types in support of international treaty-enforcement, environmental sustainability monitoring and other decision making (Thuresson 2003).

Patenaude et al. (2005) provide a detailed review of Earth Observation derived carbon estimations for UK forestry in support of Kyoto Protocol adherence, which concludes that "if remote sensing is to be the future for national inventorying, the synergistic use of contrasting approaches and the fusion of complementary datasets... should be emphasised". Investigating the same process, Kuriyama (2005) identifies potential applications of remote sensing data for compliant with Multilateral Environmental Agreements (which include the Kyoto Protocol):

> The use of EO and EO data in MEAs has great potential for contributing to the effective implementation of and compliance with MEAs. The legal norms and technical capability of EO and EO data can meet many basic requirements for implementing the obligations of MEAs. The legal framework provides EO with legitimacy for collecting and disseminating environmental data globally. It also demonstrates that EO is governed by the same legal norms as MEAs, such as the protection of the Earth's environment, equity and international cooperation.

> EO's technical capabilities, such as objectivity, homogeneity and repetitive global coverage, are unique advantages that conventional systems cannot offer. Recent technological and market developments in EO are likely to eliminate EO's limitations in cost-effectiveness and usability (Kuriyama, 2005).

Perlin (2003) notes that the function of forest surveying has changed to account for new information requirements and increased data scope: "forest assessments, once primarily concerned with measuring availability of wood, and later increasingly concerned with forest area and change in forest areas, are now moving to address the full range of benefits from forest and tree resources".

Assimilation of new data types for landscape management has been hampered by 'bottom-up' database compatibility issues and 'top-down' political constraints. Recommending resolutions to these issues, Koch (1996) states that "there is a need to build up an independent European forest inventory system", a sentiment echoed by UK foresters who state that "top-down knowledge transfer just isn't happening" and very little linkage has been made between pure-science research and operational forestry (Wilson 2004, personal communication). The same is true in Canada, where Remmel et al. (2004) find that "forest inventory methods differ by political jurisdiction, intended purpose and forest type, leading to fragmented and often incompatible data types that do not easily aggregate nationally". Addressing these issues, a new approach for National Forest Inventory was proposed by Wulder et al. (2004), joining pre-existing Landsat ETM+ data-sharing agreements (established between provinces) in a nationwide survey; Earth Observation for the Sustainable Development of Forests (EOSD). Elsewhere progress has also been made; in 2002 a panel of experts discussed strategies for linking information sources to improve sub-national, national, international and global decision making in forestry, and (Kotka IV 2002, FAO 2003).

In a sector where 'overselling' has been a problem in the past (Wilson 2004, personal communication), forest managers state that "the technical possibilities of remotely sensed data are irrelevant, because we will always need a site visit anyway" (Woodhouse 2004, personal communication). Thuresson (2003) agrees to some extent, and asserts that "for many ... important variables, such as above-ground woody biomass, growth and yield, merchantable wood, non-wood forest products and biodiversity indices, satellite data are weak or useless without sample-based forest inventory plots".

It is clear that remotely-sensed data cannot entirely replace ground surveys, but they have the potential to reveal areas of concern, which become the focus for ground-based teams. In this way the inclusion of additional data sources supports existing activities as well as augmenting capability and improving management efficiency. Woodhouse (2004) states that "one of the areas of greatest potential is the more effective use of staff in managing forests – person-hours must be used to their full potential within very tight budgets." In the UK, the primary surveying aims of stand managers are to assess diameter at breast height (DBH), measure tree spacing and species composition, year of canopy closure, mortality and stand class. Feedback from these measurements decides requirements for remedial action, influences planting strategy for new stands and controls scheduling and planning of harvesting activities.

5.3.4 Strategy and Legislation in Forestry

At the beginning of the 1980s it was reported that European forests were in rapid and worrying decline (Ulrich 1980, Schütt 1980, 1982 cited by Kandler and Innes 1994). Some researchers claimed this decline was the result of atmospheric pollution, and that it was symptomatic of a new syndrome, beyond the influence of previously identified tree diseases. Others blamed anthropogenic climatic change, acid rain or the degradation of soil resources. In response to growing concern and public pressure, several nations within central Europe commenced a programme of annual forest surveys. The German government started monitoring in this way in 1982 by sending a questionnaire to thousands of forest owners and managers asking them to categorise land into three classes: slightly, moderately or severely damaged.

In 1983 the procedure was refined to cover most of continental Europe through the use of visual assessments at maximum 16 kilometre grid spacing, and the number of classes identified through mortality or discolouration was increased (Kandler and Innes 1994).

Amid projections that timber price would fall and extra felling would be required (Meister, Schütze and Sperber 1984), research into European forest health was initiated by United Nations within the scope of the 1979 Economic Commission for Europe (ECE) Convention on Long Range Transboundary Air Pollution (Backhaus 2005, Organisation for Economic Cooperation and Development 2005). The Commission states that "early forest condition monitoring in the 1980s mainly comprised the assessment of crown condition. While this provided widespread evidence of forest damage, it became clear that more intensive investigations on site and stress factors, as well as on the biological and chemical ecosystem condition, were needed to establish the links between cause and effect" (UN/ECE, 2000).

Further methodological refinement followed new legislation ratified in 1986, and in some areas plot density approached 4 kilometre spacing (Kandler 2006), contributing to a grid of over 6,000 plots. This is known as the European 'Level 1' network, supported by 38 nations (ECE 2000). In the following years UN/ECE findings discredited original projections and largely supported newer literature which indicates that "growth rates of trees and stands in Central Europe are currently higher than have been recorded at any time in the past" (Kandler and Innes 1994). In academic circles, the widespread decline of forest health has been exposed as a myth, but debate is still active in the popular media and in some quarters of forestry administration. UN/ECE clarify the position of forest monitoring policies by stating that "in the future the monitoring data may contribute to research and policy decisions in such important areas as biodiversity, climate change and carbon sequestration" (ECE 2000).

UK forest monitoring, survey and inventory is administered by the Forestry Commission and reported via the annual National Woodland Survey, which was initiated as far back as 1924 (Forestry Commission 2004, Jones et al. 2003). New European requirements to monitor woodlands and forests were integrated with this pre-existing programme. Forestry Commission state that collection and collation of survey data is important because "information on the size, distribution, composition and condition of woodlands is essential for developing and monitoring policies for the sustainable development of woodlands and the countryside" (Forestry Commission 2004). To update and strengthen legislation, the 1997 EC Treaty (article 138b) called for the development of a "coherent forest strategy for Europe". The treaty aims to promote multifunctional forestry with "ecological, economic and social sustainability" within the wider context of agreed principles and treaties, including UN/ECE agreements such as the Kyoto Protocol.

More than ever, stakeholders are included in the design phase of local, regional, national and international policy. Higman et al. (2005) discuss potential stakeholders of European woodlands, and conclude that the following groups and individuals are affected by forest policy and have a legitimate claim on the resource. To reflect this, planning-stage consultation is often desirable and appropriate, but not easy or even practicable - Higman et al. (2005) state that "if people or groups have legal or customary rights to the forest resource their free and informed consent to forest operations [such as harvesting] must be obtained". For these purposes, stakeholders are listed below.

- People who live in the forest, or nearby
- Visitors and settlers from further afield
- Forestry officials, workers and their families
- Local businesses with related interests
- Managers of forestry companies
- Environmentalists
- Politicians
- Citizens (including those who never plan to visit the resource)[13]
- Consumers of forest products

[13] See section 4.2.3.4 for a detailed discussion of non-use, or passive value types.

5.3.5 **Monitoring Forests**

Within well-developed and secure procedural and legal frameworks, Chaudhary (1999) notes that "there is a dire need to effectively manage the forest and biodiversity ... for economic, cultural and political stability ... as well as to meet international obligations". The main political driver may be legislative compliance but the potential benefits of this policy-making are broad ranging and multi-disciplinary.

Benefits of large-scale forest monitoring feed into several strands of policy including treaty-enforcement, environmental legislation, landscape management and resource management. In defence of continued monitoring, the Economic Commission for Europe presents the following conclusions.

> The data gathered ... and their evaluation are of interest for policy-making processes not only in the field of environmental protection but also for different kinds of forest policy items, such as sustainable forest management, biodiversity in forest or the effects of climate change on ecosystems. Thus the monitoring system provides a cost-effective multifunctional approach (UN/ECE 2000).

The challenge for foresters and environmental scientists is therefore to collect high quality spatial data in order to effectively address research questions and legislative responsibilities in an accurate, cost effective and repeatable way. When cost, coverage and technical capability are objectively evaluated, it seems that satellite data is an appropriate tool for forest survey, assessment and management (Hyyppä et al. 2000).

Modelling by Tomppo and Czaplewski (2002) suggests that global forest coverage can be achieved using Landsat for approximately US $254,000, but that verifying such data with minimum-coverage field plots introduces a further cost of US $18.7 million. Using field data alone, the authors predict costs of up to US $100 million for global coverage, which means that Earth Observation data has the potential to save around US $80 million per year in global-scale forest monitoring. In the UK, Patenaude et al. (2005) estimate costs for ongoing forest monitoring. A single national dataset acquired by ground survey would cost £3.5 million. Based on operating costs of £250/km^2, aerial radar coverage would impose a cost burden of £7 million for the same coverage. Comparable data costs for space borne remote sensing (optical or radar) are estimated at £3000 per survey (Patenaude et al. 2005).

In some nations, satellite data is well-integrated with national forest survey procedures and processing streams, and automated data collection regimes are in place. Finland was the first nation to use satellite data on a routine and operational basis for forest monitoring (Tomppo 1991, Hyyppä et al. 2000), and national surveying is achieved using an automatic *k*NN process. The *k* Nearest Neighbour approach (*k*NN) approach assigns each unknown pixel in a digital image to the class of the most similar reference pixel, using a feature-space comparison. The methodology has become popular because "it has proved timely, cost-efficient and accurate, both in the Nordic countries and in initial trials in the US" (Tomppo 1991, McRoberts et al. 2002, Ek 2003). If space-borne sensors contribute to more complete, representative or repeatable surveys (which themselves lead to improved decision-making ability and more accurate information to support or influence policy), then data sources inherit added value through this exploitation, as discussed in Chapter 4. Although many forest applications appear commercial in nature, credit for the non-market benefits of effective management can be attributed to contributory data, including Earth Observation. This value-chain (which is known as the 'value-inheritance' concept) is omitted from market-driven econometric analyses, so novel ways of capturing value are required.

5.4 Forestry Survey

5.4.1 Introduction

To assess the validity of value-inheritance concepts in the context of forestry, two case studies were conducted: a consultation with forestry professionals, and an image processing experiment based in Scottish and Finnish forest districts. For the first case study a questionnaire was developed and disseminated in order to define and explore the relationship between foresters and geospatial information.

5.4.2 Aims

The questionnaire will:

- Identify how Earth Observation is currently used in UK forestry activities
- Discover the degree to which forestry data requirements are met with operational Earth Observation missions
- Assess the popularity of new data sources alongside traditional approaches
- Discover inhibiting factors and investigate user experiences
- Explore optimal data requirements in temporal, spatial and spectral terms

The questionnaire included eight open questions to allow respondents to freely express opinions and reveal information which would not suit pre-defined answers. A further three questions required users to check boxes to indicate familiarity with data, or to give permission for further contact in the course of the research. The questionnaire was brief and very simple to complete.

5.4.3 Questionnaire Structure

5.4.3.1. Design

Good questionnaire design constructs a relationship between respondent and surveyor which helps to improve response rate. The questionnaire design should be highly structured to allow simple collection of comparable data from large numbers of respondents. Although ease of data coding is a consideration, in this case it is essential that users feel able to express their experiences, so the majority of questions are open. The survey issued in the course of this research was designed following the 'egg' model of participant management (adapted from McKeown 2003, Figure 5.8).

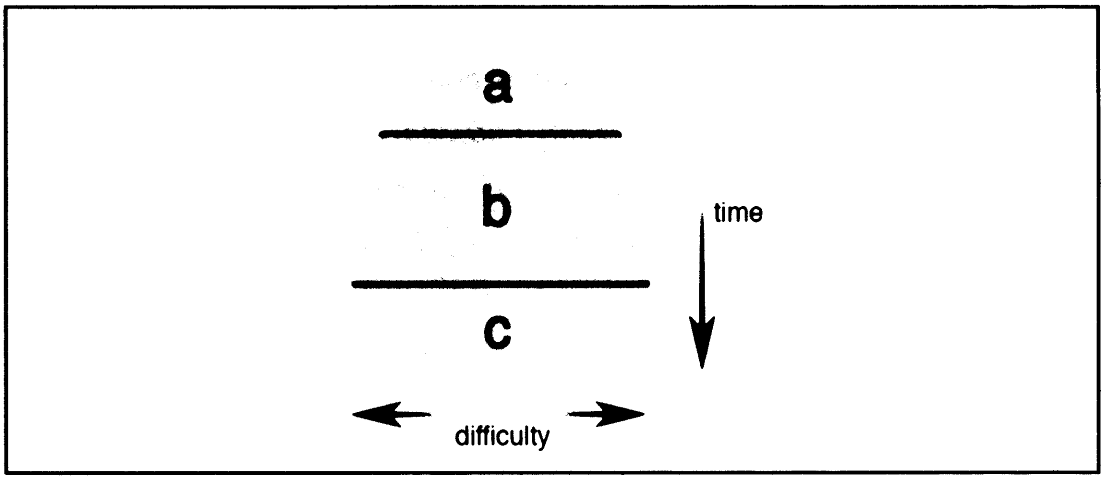

Figure 5.8 The 'egg' model of survey participant management ensures that challenging questions are not placed too early.

An effective survey comprises three parts, completed sequentially: entry (Figure 5.8, section a), discussion or task (section b) and lead-out (section c). The most challenging sections of the survey are placed towards the end of the task phase to allow respondents to feel comfortable in their role. Challenging questions presented too early threaten users and they may abandon the survey. The 'egg' form ensures that participants are guided out of their comfort zone. The model also helps to avoid respondent suspicion. The entry phase allows users to progress rapidly, answering simple filtering questions, while later stages of the survey are more challenging. Finally, the survey returns to a simpler set of questions to reduce stress for participants and lead to a feeling of closure. McKeown (2003) states that surveys are "most likely to be completed if they are easy on the eye, relevant, logical and as short as possible".

5.4.3.2. **Dissemination**

Electronic mail was used to distribute the questionnaire to a small number of targeted recipients who represent major agencies, research institutions and other interested parties. Survey forms were available as Microsoft Word documents. Completed forms could be emailed or printed and sent by post. The recipient list was assembled using academic publications, research programme involvement, conference attendance and personal recommendations. By eliminating disinterested recipients and focussing on a small expert group, higher response rates can be achieved (Dixon and Leach 1978). In the six months between September 2003 and March 2004, 59 individuals received the survey. 16 forms were returned, which represents a response rate of 27 per cent. The following institutions and agencies were contacted.

- UK Forestry Commission
- UK Forest Research
- UK Forest Enterprise
- Centre for Ecology and Hydrology
- European Forest Institute
- Swedish National Board of Forestry
- Finnish Forest Research Institute
- USDA Forestry Service
- Durham University
- Canadian Forest Service

In addition to mailing lists of recipients, an invitation was included in the covering letter of the questionnaire which asked users to forward the survey to colleagues. This request increased survey readership and helped to spread awareness within undocumented personal and social networks. The final question invited respondents who had an interest in the research to participate further by agreeing to be contacted and interviewed. UK site visits were undertaken alongside telephone conversations and email correspondence with survey respondents. In February 2004, seven follow-up interviews were held at the Centre for Ecology and Hydrology (Monkswood), Durham University, and Forestry Commission sites at Kielder and Galloway.

5.4.4 Questionnaire Discussion

5.4.4.1. User Data

Q1: What is your role in your organisation? What responsibilities do you have?

Q2: What strategies for forest management does your organisation currently employ?

The first survey question gathers information about the spread of professional roles and responsibilities among respondents. Outcomes of these questions inform estimations of bias and assist in deciding whether participants can be considered a representative sample of foresters in general. Almost 60 per cent of respondents in this case had operational management responsibilities, and many of the others stated that they were responsible for forestry research, local or national policy. The second question surveys operational forest management strategies. The profiles of invited participants would suggest that a mixture of resource stewardship (the responsible management of national forests, for example), scientific research and commercial plantation forestry responses would be received. This was broadly the case, although it is notable that several survey participants mentioned objectives of achieving sustainability in forest management.

5.4.4.2. **Limitations and Solutions**

Q3: What limitations and problems have you encountered with data collection and management?

Q4: Have satisfactory solutions been found?

The third question asks respondents to describe problems or limitations they have encountered personally, and the fourth enquires about the success of implemented solutions. Participants commented frankly about problems they have encountered. Responses addressed three main themes: the absence of suitable data, excessive financial cost and timeliness of data acquisition. One participant, who works as a forestry survey development officer, noted that "it is difficult to find out what data is on the shelf, and how best to use it" (Snape 2004). A forest research officer stated that the greatest limitation was the "cost of purchase, and data licensing complications", before expressing frustration at the lack of solutions; "you pay the money, or no data!" (Milne 2004). This frustration was shared. Häusler (2004) notes that in the context of the Forestry GMES Service Element (GSE), "the most promising field is combining in-situ data (forest inventory) with Earth observation-based mapping ... [but] forestry users in government organisations who are willing to implement Earth Observation and GIS solutions cannot allocate the necessary budgets". Watt (2004, personal communication) comments that university research linkages have helped to motivate proof-of-concept studies in UK forestry, but operational foresters are reluctant to adopt satellite data because "Earth Observation is seen as a real money-pit". Woodhouse (2004) confirms that "so far, we [the Forestry Commission] have seen a lot of expenditure and not a lot of benefit".

5.4.4.3. **Change and Improvement**

Q5: What could be done to improve the accuracy, efficiency and simplicity of forest management?

This question elicited varied responses. Snape (2004) calls for improvements in data access and processing, consistent with interview outcomes that indicate foresters have been neglected by value-adding private sector companies; one individual stated "the remote sensing companies have a job to do to meet our requirements, then they can enjoy our business" (anonymous 2004). Häusler summarises the frustrations of other respondents (Leckie and Rosengren, for example).

> [Foresters need] better ground resolution of Earth Observation data (because they often work at 1:10,000 scale), sustainable availability of data through Earth Observation mission continuity, fast access to data at affordable prices, standardised value adding chains for Earth Observation data (including pre-processing) and service chains customised by forest users and maintained by professional service providers (Häusler 2004)

Rosengren (2004) notes that the partial failure of the Landsat 7 Enhanced Thematic Mapper instrument is a major limitation for European foresters, which may lead to "a lack of yearly, cloud-free, optical high resolution satellite images over large areas (country wide) during vegetation season." Beyond operational issues, Wilson (2004) questions "glamorous" new approaches and states that in forestry there remains a need to "define why the information should be gathered, what is its *true* value and how it will be used". Addressing the concerns of many foresters, Suarez (2004) states that "there is no need for [them] to be defensive ... there will always be a need for site visits, remote sensing is a complementary approach". It seems clear that operational foresters use satellite images to more effectively deploy staff to areas with identified complications. Wilson (2004) questions the need for costly monitoring in forestry; "the question of what we need to know and why is very important – why sample a stand of trees with no timber value?" Slee (2004) comments that a major challenge emerging for foresters is the creation of a new kind of forestry that is compliant with "various pieces of enabling and constraining legislation". It is this legislation that calls for intensive monitoring of even non-commercial forest compartments.

5.4.4.4. **Forestry Data Requirements**

Q6: What forestry variables would you ideally like to work with?

Survey respondents were asked about what data would best support their operations. Responses were extremely variable, which reflects the open question form and the broad range of specialist activities within forestry. Some responses focused on biophysical parameters such as stand and ecosystem phenology, leaf area index and standing biomass. Others were more basic and analogous to 'traditional' forestry variables such as diameter at breast height (DBH), canopy closure, yield class and timber volume. One recipient called for basic data because "forest managers just need to know what is growing where, and at what rate" (Snape 2004). Another class of responses sought physical information such as tree age, average height and species composition. The location and extent of change through processes such as clear-cutting or wind-throw was requested by several participants. Several respondents commented that parameters from Earth Observation data sets need to be more closely integrated with models of carbon sequestration or tree growth.

5.4.4.5. Update Frequency

Q7: How often should the data on these variables be updated? In order to work effectively, what do you really need to know?

Users were invited to suggest the optimal update frequency for the variables they suggested for question six. The most common requirement was for a five-year update frequency, followed by requests for annual monitoring. Some suggestions for other frequencies were also received, ranging from daily, weekly and monthly coverage to a ten-year revisit frequency. Consistent with typical ground-based management plans and surveys (Wilson 2004, personal communication) five years is a typical update requirement for operational forestry. Monitoring for fire damage, the effects of pathogens or illegal felling require more frequent updates. Snape (2004) notes the validity of a programme of post-event data collection; "it would be useful to monitor wind-throw following catastrophic events, and satellite data would help". Monitoring for carbon-accounting or biosphere process monitoring requires macro-level surveys on an annual basis (Slee, Häusler 2004).

5.4.4.6. Current Behaviour

Q8: What sources of data does your organisation currently use? [checkboxes]

Almost 80 per cent of survey respondents regularly use ground survey data, in most cases supported by Global Positioning Systems (GPS) and Personal Digital Assistants (PDAs). 64 per cent use aerial photography, and an equal proportion use satellite data. Among Earth Observation data users, almost half use Landsat and a similar proportion have used very high resolution data from platforms such as Quickbird and IKONOS. Several survey respondents comment that very high resolution satellite data is as useful as aerial photography for the majority of tasks.

5.4.5 Interviews and Site Visits

Following the deployment of the questionnaire among forestry professionals, individuals who expressed an interest in taking part in further work were contacted. Of those, four groups emerged within the UK; firstly the Forest Research and academic study group based at Durham University, second the Forestry Commission management team at Kielder Forest District, third the operational foresters at Galloway forest district, and finally researchers at the Centre for Ecology and Hydrology at Monkswood. In addition, forestry experts from Sweden, Finland and Canada were interviewed via electronic mail. The outcomes of these site visits and supplementary questions provide additional insight into the needs and frustrations of foresters at several levels of seniority, both in the UK and abroad.

UK and Scandinavian participants noted that several key factors have led to greater urgency and advancement in technological approaches to forestry in Nordic countries. Strong motivations for effective and applied forest management schemes are related to the dominance of forest as a national land cover; 74 per cent of Finland is covered with productive forest and the nation is otherwise poor in natural resources (Hakkila 2006, Forestry Commission 2006). Taxation and environmental strategies also increase the role of forestry in Nordic economies, and growth in Finnish and Swedish strategic forestry is linked with a shift towards biomass-fuelled energy provision and connected government budgetary considerations (Ericsson et al. 2004). In addition, socio-cultural considerations of forest resources are very different in Scandinavia.

> Sweden and Finland have a long history of economical exploitation of forest resources. Forest land has been regarded foremost as an economic resource, and legislation has been in place for almost a century to ensure that productive forest land is managed to preserve long-term economic output. Forest products represented 13% and 26% of total exports in 2000 in Sweden and Finland, respectively, indicating the sector's importance to the economies of these countries (Ericsson et al. 2004)

In contrast to information- and technology-intensive Scandinavian forestry policy, traditional functional roles continue to dominate activities in the UK; planning, management and harvesting working groups do not effectively share information. UK foresters suggest that there has been little cross-cutting investigation of data requirements between sub-disciplines. Several interviewees agreed that UK Forestry Commission higher management "have little appreciation of the real-world cost" of research and development, which is typically undertaken by Forest Research in association with Universities. Referring to the position of Earth Observation as a tool for forest management in the UK, one participant comments.

> On the EO side of things, the last round of the National Forest Inventory used aerial photos only (and paper ones at that) - so we [the Forestry Commission] have costs for that. The next round will use digital aerial photos, and FC has an agreement with the Ordnance Survey for provision across Great Britain. All other experience of satellite images, LIDAR, etc. has been on a trial basis, and therefore costs of acquisition will not be representative (anonymous 2006).

A Forestry Commission employee at Galloway Forest District remarked that in terms of information capture, the disciplines of planning, management and harvesting are still considered "totally separate" (anonymous 2004). Lack of an integrated flow of processing means that collection of duplicate data is common in UK forestry. Forest surveyors may use satellite data and aerial photography to check compartment boundaries, but the purchased data is not routinely shared with managers who commission surveys to check the health and growth of stands. The same area may be surveyed a third time to estimate compartment yield classes and species composition.

Interview responses reveal foresters' expectations regarding Earth Observation data. Most participants did not want or expect a step-change in operational capability; Woodhouse (2004) states that foresters "just want products that are relevant, delivered at a price we can afford, in a means that is usable". In fact, the most desirable outcome for forest managers was to be able to deploy staff more effectively, in areas where problems had already been identified. One forester comments "we already do what is necessary;

we're in pursuit of cheaper, quicker and more effective approaches". Management efficiency could be significant for some applications; to survey 50,000 hectares of forest in Kielder, Wilson (2004) notes that "2 satellite images are operationally equivalent to over 200 aerial photos, and a *lot* easier to manage". This applied knowledge is consistent with the academic work of Tomppo and Czaplewski (2002) and Patenaude et el. (2005), which suggest that Earth Observation datasets can be orders of magnitude cheaper than aerial survey.

5.5 Exploratory Case Studies.

5.5.1 Introduction and Site Character

To further explore problems of data capture in forestry and to evaluate the technical requirements of operational use, two exploratory image processing case studies were conducted in locations which are very different in character. Galloway Forest is located in south-west Scotland (around 55°5'N 3°50'W, illustrated Figure 5.9). The Forestry Commission established the site in the 1940s; it is now the largest forest district in the UK with an area of 97,000 hectares. This represents 20 per cent of all Forestry Commission land in Scotland (Forestry Commission 2006). Planting in the area is 80 per cent dense unmixed Sitka Spruce, with the remaining 20 per cent comprising mixed stands of Sitka Spruce and Lodgepole Pine. Kivalo Experimental Forest Park in Finland (location 66°21'N 26°44'E, illustrated Figure 5.10) was established in 1924 and is dominated by semi-natural Norway Spruce and Scots Pine stands, mixed with small areas of Downy Birch (Koivuniemi 2006, personal communication). Boreal peatland and semi-inundated mires account for around 35 per cent of total area. The Kivalo park forest covers an area of 15,000 hectares, which is mostly 200-300 metres above sea level. Forests in this area are subject to intensive monitoring by Metla, the Finnish national forestry service, which maintains three sites which contribute to the Economic Commission for Europe (ECE) Level 1 Forest Condition Monitoring Programme (ECE 2000, Metla 2006).

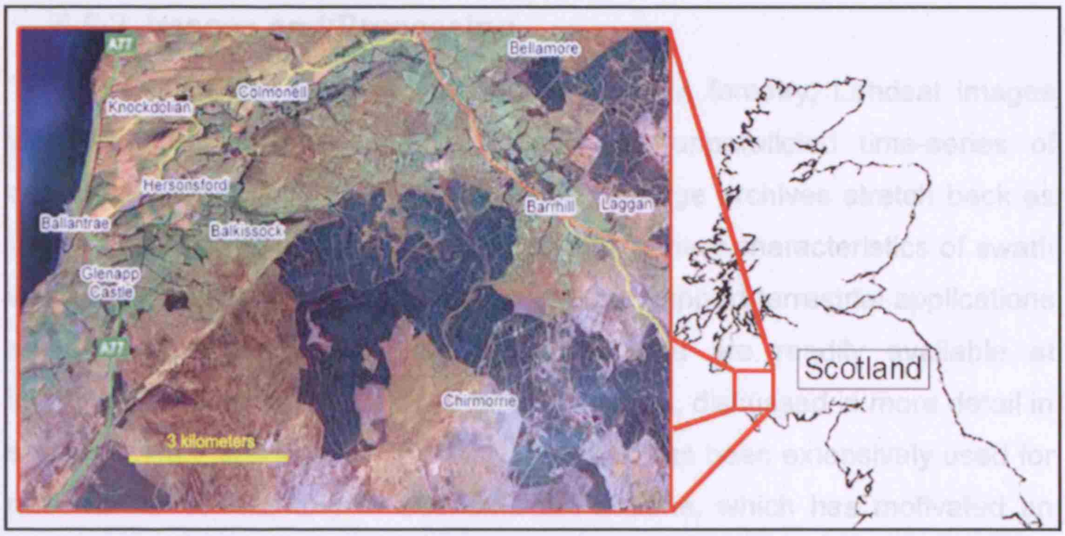

Figure 5.9 Location of Scottish image interpretation study. The area includes a discrete forest compartment covering approximately 102 hectares. The study does not represent the entire Galloway Forest District (© Google Maps 2006).

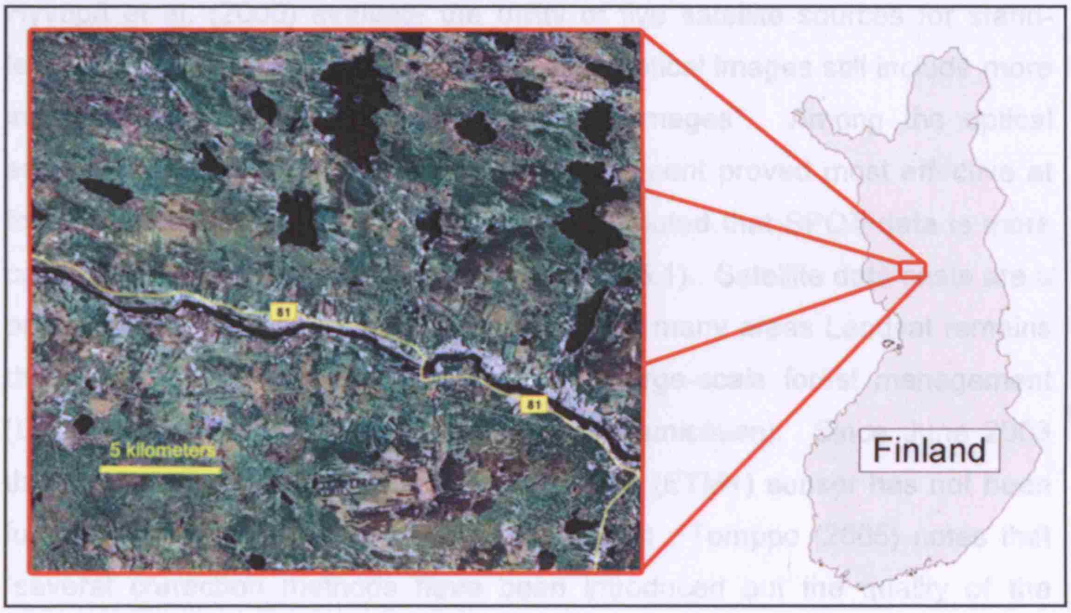

Figure 5.10 Location of Finnish image interpretation study. The satellite image is bisected by the Kemijoki River and centred on the town of Vanttauskoski in central Northern Finland (© Google Maps 2006).

5.5.2 Images and Processing

To exemplify Earth Observation data sources in forestry, Landsat images were chosen for four reasons. Firstly, an unparalleled time-series of comparable data is available; Landsat MSS image archives stretch back as far as mid-1972 (Campbell 1996). Secondly, sensor characteristics of swath width and spectral coverage were designed to support terrestrial applications such as vegetation monitoring. Thirdly, data are readily available at incremental cost through US federal data policies, discussed in more detail in section 4.1.5.1 and 4.3.1.2. Fourthly, Landsat has been extensively used for national forest inventory in Scandinavian nations, which has motivated an understanding of sensor capabilities and limitations which is well-represented in academic literature. Finland was the first country to implement operational monitoring of this kind using Landsat (Tomppo 1991, cited by Hyyppä et al. 2000).

Hyyppä et al. (2000) evaluate the utility of five satellite sources for stand-level forest management and conclude that “optical images still include more information for forest inventory than radar images”. Among the optical sensors tested, the SPOT multispectral instrument proved most effective at forest detection and classification, but it was noted that SPOT data is more costly than Landsat imagery (illustrated Table 5.1). Satellite data costs are a primary concern of operational foresters, so in many areas Landsat remains the most suitable satellite data source for large-scale forest management (Donoghue 2004, Watt 2004, personal communication). Since June 2003 the Landsat Enhanced Thematic Mapper Plus (ETM+) sensor has not been fully functional due to a spacecraft malfunction. Tomppo (2005) notes that “several correction methods have been introduced but the quality of the product is not the same as without the failure”. Although Landsat Thematic Mapper (TM) data is still available, other platforms can be used to supplement archive data and ensure continuity of coverage. In addition to providing a cost comparison, Table 5.1 summarises spectral and spatial characteristics for SPOT, Landsat TM / ETM+ and Disaster Monitoring Constellation sensors.

Table 5.1 Spectral characteristics, spatial resolution and price per km^2 of satellite data sources used for forest monitoring (USGS 2006, DMCii 2006, SPOT Image 2006). Currencies with asterisks converted at spot rate US $1.32 per €.

Sensor Name	Band	Wavelength (μm)	Ground Pixel Size (m)	Cost (€ per km^2)
SPOT XS (1-5)	1	0.50-0.59	10-20	0.334-0.750
	2	0.61-0.68	10-20	0.334-0.750
	3	0.79-0.89	10-20	0.334-0.750
	4	1.58-1.75	10-20	0.334-0.750
Landsat TM / ETM+	1	0.45-0.52	30	0.104-0.196 *
	2	0.52-0.60	30	0.104-0.196 *
	3	0.63-0.69	30	0.104-0.196 *
	4	0.76-0.90	30	0.104-0.196 *
	5	1.55-1.75	30	0.104-0.196 *
	7	2.08-2.35	30	0.104-0.196 *
UK-DMC	1	0.52-0.60	32	0.013-0.111
	2	0.63-0.69	32	0.013-0.111
	3	0.76-0.90	32	0.013-0.111

Five images were processed to illustrate data characteristics and monitoring potential of Landsat. Table 5.2 shows the acquisition dates and location of images.

Table 5.2 Images used to illustrate Landsat forestry management capabilities.

Acquisition Date	Sensor Name	Spatial Coverage
15 July 1979	Landsat MSS	Kivalo, Finland
20 July 1987	Landsat TM	Kivalo, Finland
26 June 1995	Landsat TM	Galloway, Scotland
17 July 2000	Landsat ETM+	Galloway, Scotland
27 May 2002	Landsat ETM+	Kivalo, Finland

In Scotland, five years of human intervention in forest management can be seen in Figures 5.12a and 5.12b. Dense plantation forestry is clearly visible using pseudo true colour composite images of bands 1,2 and 3. As part of a forest management strategy, images of this kind can be integrated with the GIS layers already maintained by the Forestry Commission. An example of the Forestry Commission compartment database for this area is shown Figure 5.11. Images of the Kivalo Forest Park in Finland allow visual assessment of 13 years of change in an environment that is less densely planted than Galloway (Figures 5.13 and 5.14). Earth Observation data contributes to management of spatially extensive forestry zones by allowing timely detection of problems such as fire, wind-throw or disease which support the more efficient and focused allocation of staff and resources.

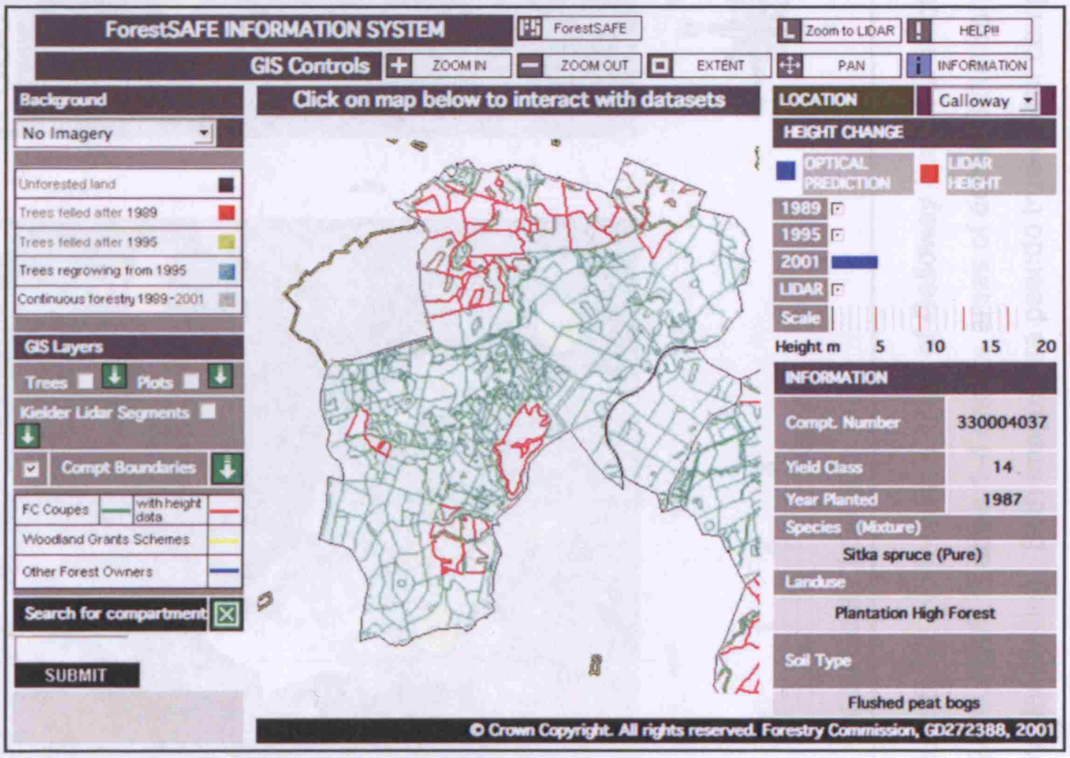

Figure 5.11 Geographic Information Systems are operational within the UK Forestry Commission; this example depicts the discrete compartment illustrated in Figures 5.12a and 5.12b. Polygon colour represents characteristics such as felling date, species composition, yield class, substrate type or tree height (Watt 2004 personal communication, © Crown Copyright 2001).

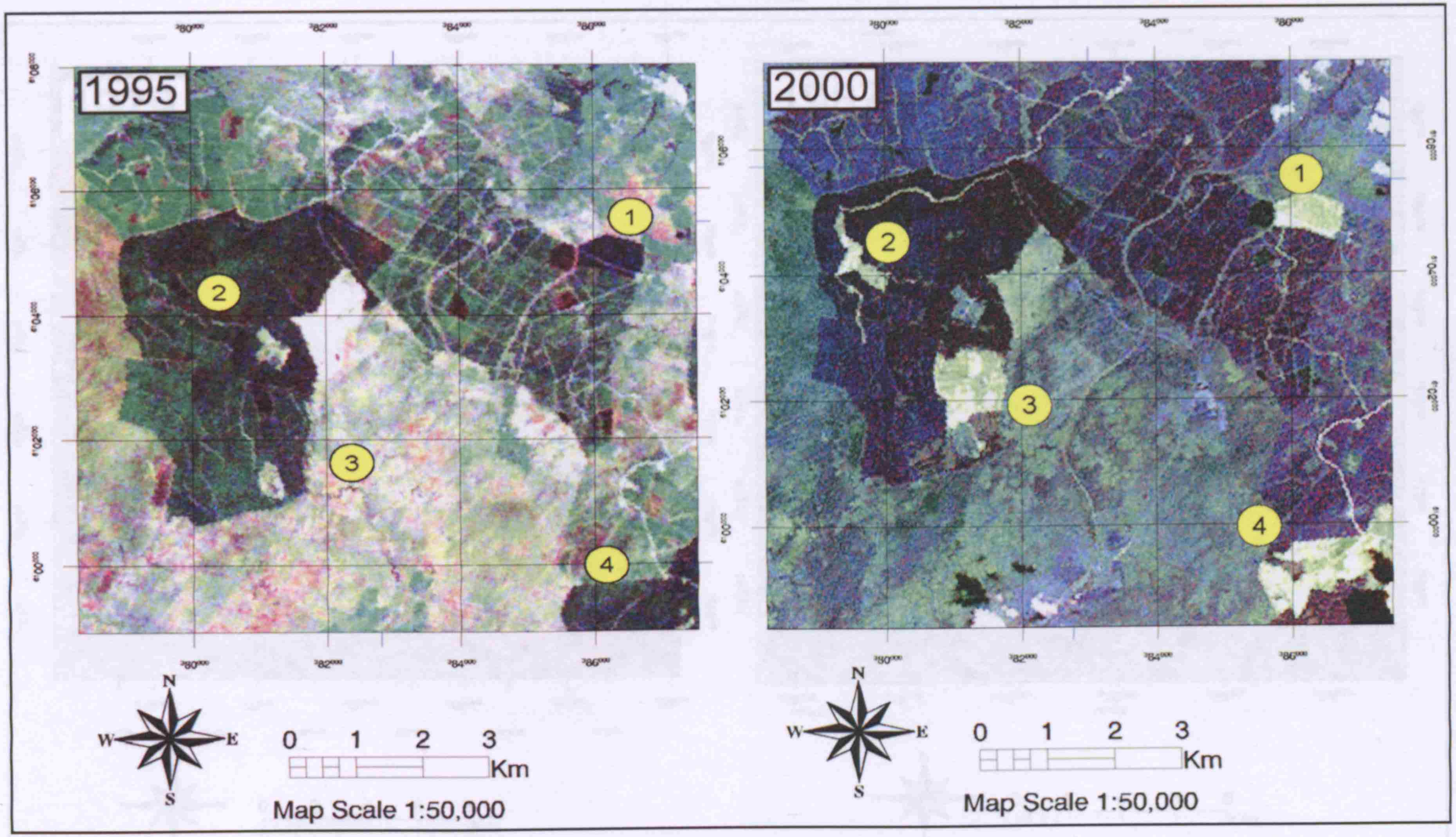

Figure 5.12a and Figure 5.12b North-east section of Galloway Forest District sensed by Landsat Thematic Mapper (1995, left) and Landsat ETM+ (2000, right). Labels 1-4 denote areas of dense Sitka Spruce land cover, where spectral response has been significantly altered by clear-felling. Both images are pseudo true-colour composites of bands 321 representing RGB.

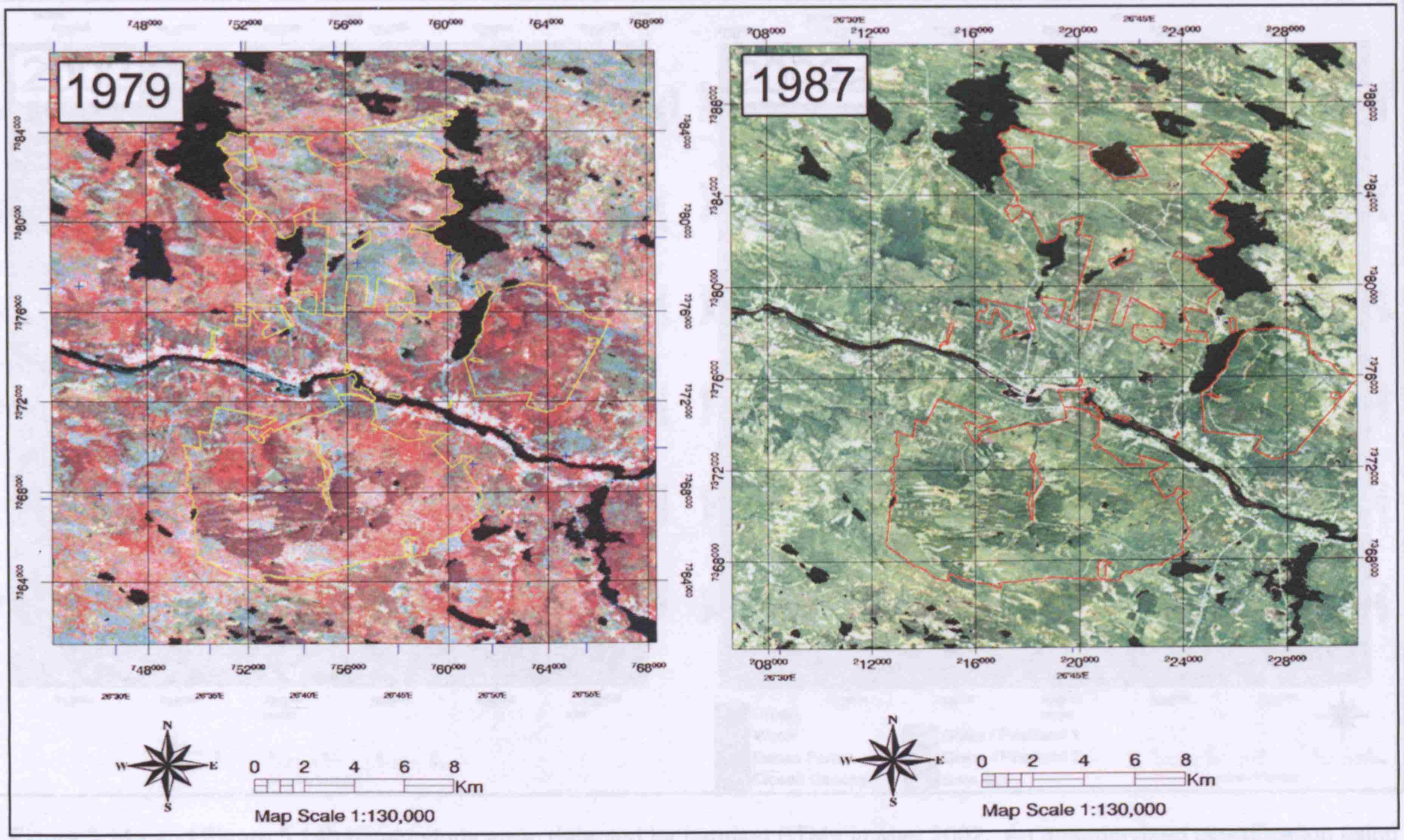

Figure 5.13a and Figure 5.13b Kivalo study area, Landsat MSS and TM. Yellow and red lines delineate the Forest Park boundaries. Areas of dense forest are spectrally distinct as darker shades; some are visible in the lower centre of the images.

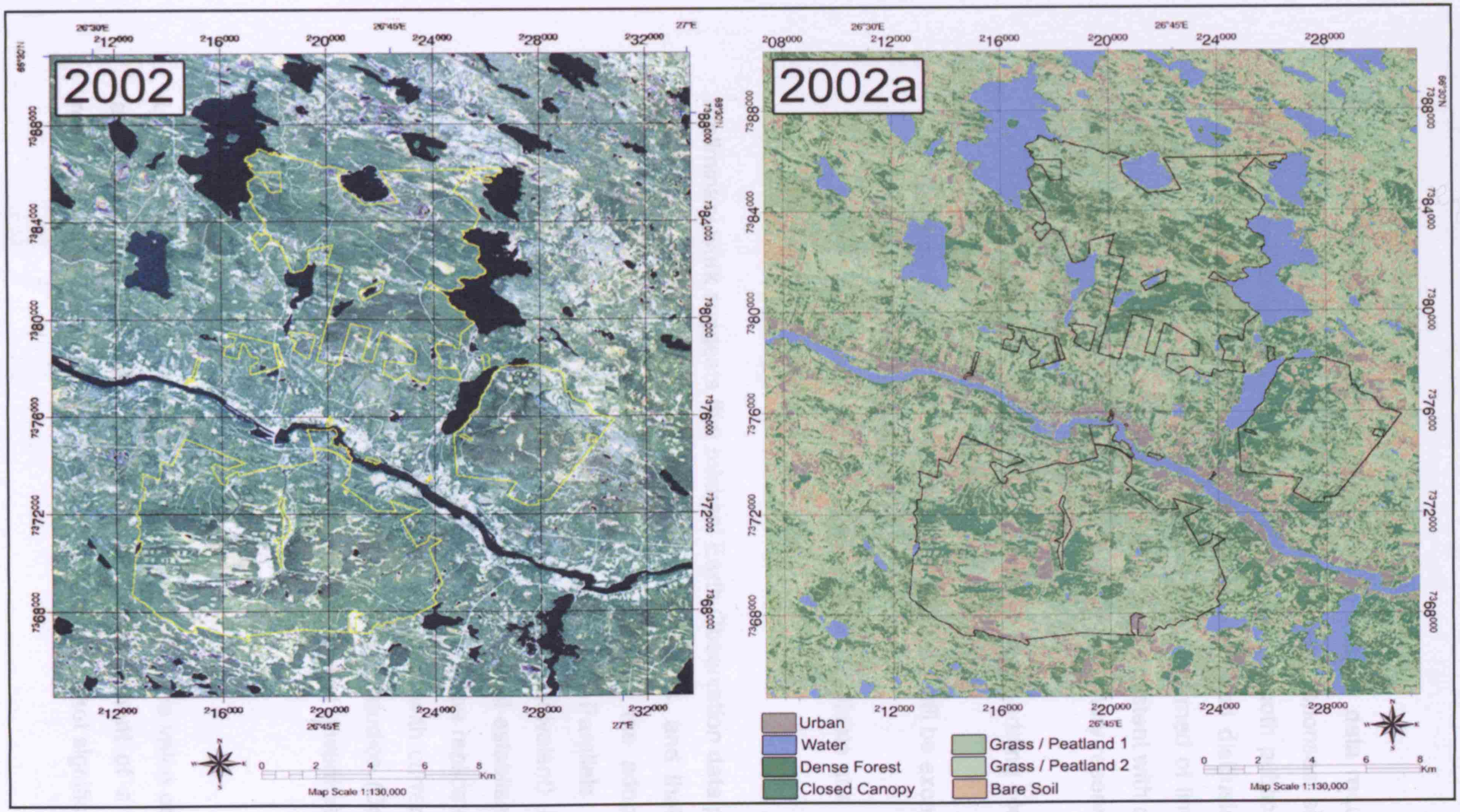

Figure 5.14a and Figure 5.14b Kivalo study area, detected by Landsat ETM+ in May 2002. An unsupervised classification using seven classes reveals dense forest and closed canopy. Dense forest comprises mature trees with open canopy; once canopy closure occurs the utility of optical remote sensing reduces and forest attributes are less reliably derived (Suarez et al. 2005).

5.6 Conclusions

A detailed Forestry case study was used to explore data requirements of forest monitoring using Earth Observation. Survey responses, site visits and interviews encountered a wide range of users from both public and private sectors; some were enthusiastic, others confused and disillusioned. They had been sold inappropriate data, had not been informed of limitations and had received inadequate after-care in the past. Consistent with other studies (such as Millard et al. 1998), users expressed five primary reservations about Earth Observation data.

- Poor access to data (directly and through value-adding companies)
- Incomplete knowledge of what data is available
- Uncertainty about cost (and a suspicion that it will be excessive)
- Concerns about timeliness of data
- Frustration that 'standard' products are not available at a manageable and consistent price

Preliminary work suggests that minimal Earth Observation data processing is required to yield relevant and representative results, and that institutional inertia and other organisational issues may inhibit the adoption of new approaches within UK Forestry Commission. Parallels drawn with Scandinavian forestry suggest that Landsat (or equivalent) images offer optimal cost / performance trade-offs, and that well-established validated processing strategies are in place which could easily be replicated in the UK. Such procedures have been successfully integrated with current GIS-based digital forest management approaches in academic studies (Donoghue and Watt 2006, ForestSAFE 2005) and national forest inventories (Tomppo 2005).

5.7 Forestry Model of Value

Use of Earth Observation for forestry contributes to the value of data directly and indirectly by enabling more effective management of a Public Good resource with climatic, biological and cultural non-market significance.

> The main case for government intervention in forestry is to deliver public good outputs in the form of urban and peri-urban amenity, recreation and biodiversity (CJC Consulting et al. 2003, cited by Slee 2003).

Although estimations of marketed and non-market forest value are available (Jones et al. 2003, Slee 2003) the contribution of Earth Observation is poorly captured and incompletely understood. The 'knowledge gap' between Earth Observation providers and foresters prevents the fair and effective evaluation of new approaches. No accessible mechanism is in place to assist forest managers in decision-making regarding Earth Observation, and data suppliers have not prioritised market development because the primarily non-market outcomes identified by Slee (2003) lead to poor return-on-investment.

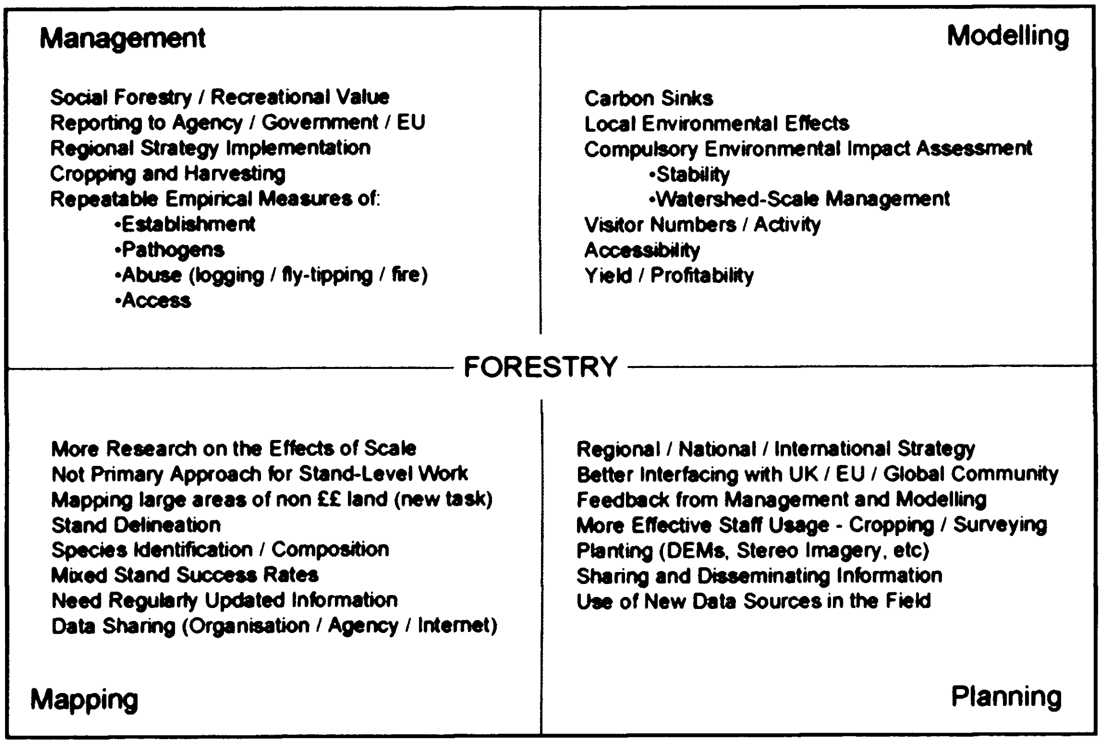

Figure 5.15 Value framework developed using forestry questionnaires and interviews, for assessing the potential contribution of Earth Observation data within management, modelling, mapping and planning activities. Regional weighted aggregation of responses (in the centre of the model) ensures that multiple-use data sets are only purchased once. An implementation guide is provided in section 5.7.1.

A framework for investigating the value of Earth Observation within forestry can be developed using interview outcomes and survey responses mapped as an activity-based organogram (shown Figure 5.15). Development of this leads to a model which provides weighted assessments of the suitability of Earth Observation data through a novel and non-technical problem-solution approach which is based in the four categories of management, modelling, mapping and planning.

5.7.1 Model Implementation

The first stage of the model is to assess the availability and cost of data; where possible, examples of products should be provided to forestry specialists before the model is introduced. For some applications, an invitation to tender structure can be used to assess costs and the performance of different suppliers. In large organisations such as HM Government or the Forestry Commission, an audit should be undertaken at this stage to establish user-groups for data, to refine internal data policy governing sharing and duplication, and to identify and evaluate any suitable data already held. The outcome of this stage is a table of available data, incorporating key variables such as (in the case of forestry): price per hectare, pixel size, geolocation and metadata, available wavelengths, repeat interval, and licencing or data policy restrictions.

In the next stage, managers and technical specialists each address one sector of the model, with reference to the available data. Through focus groups, new sources of information are ranked based on the extent to which they address operational problems, introduce new capability and allow efficiency savings. Respondents are free to add issues to the model or abstain from questions they do not feel qualified to answer. To ensure that performance measures are consistent between assessment teams, analytical mechanisms such as decision matrices, alternative futures analysis (AFA) and analysis of competing hypotheses (ACH) should be implemented where possible (Heuer 1999, Good et al. 2005, Sanfilippo et al. 2007). These mechanisms form the basis for an assessment of the Faster-Better-Cheaper (FBC) impact of Earth observation on forestry (Paté-Cornell and Dillon 1998).

Note that the outcome of this model phase depends heavily on the representation of a complete and unbiased list of data providers and their products.

Finally, results from the four subject areas are collated and aggregated at regional level; in some areas management for recreation will be a higher priority, in others ecological planning and mapping may be prioritised. To ensure consistency, weighting of the four model elements could be directly proportional to the allocation of personnel-hours to each activity. Similarly, weights could be linked with budget allocation, as directed by Annual Spending Round outcomes. As regional results are finalised, they are weighted in line with current objectives and policies as laid down in the regional forest management and design plans submitted to UK Forestry Commission. This process ensures that effort is focused on areas of greatest benefit, and that spending and research is consistent with organisational aims and objectives (Forestry Commission 2004). This approach for assessing value provides a non-technical means for indirectly capturing the replacement cost and opportunity cost of Earth Observation data within forestry. What is the cost of the nearest equivalent analogue? What other spending would be prevented by allocating resources to Earth Observation development?

This methodology provides a new conceptual approach to non-market benefit-cost assessment[14] in forestry (which can complement more traditional CBA assessments). The approach also clarifies ways in which forester's use of Earth Observation contributes to its general value in marketed and non-market contexts outside forestry.

5.8 Generalised Model of Value

The data requirements of foresters are well-specified and aim to fulfil industry-wide objectives, but the proposed approach for capturing hybrid value-types (including those which straddle marketed and non-marketed

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[14] Appendix 3 provides a diagrammatic value model implementation guide.

categories) is more general in nature. It is possible to adapt the model developed within forestry for general use. Many applications with geospatial components include sub-disciplines of management, mapping, modelling and planning. Issues of what, where, how and when are common. The generalised value model is shown in Figure 5.16. In order to test the success of model generalisation for value-capture, the contribution of Earth Observation (and it's consequent value) is assessed in the humanitarian aid sector, where the model is applied.

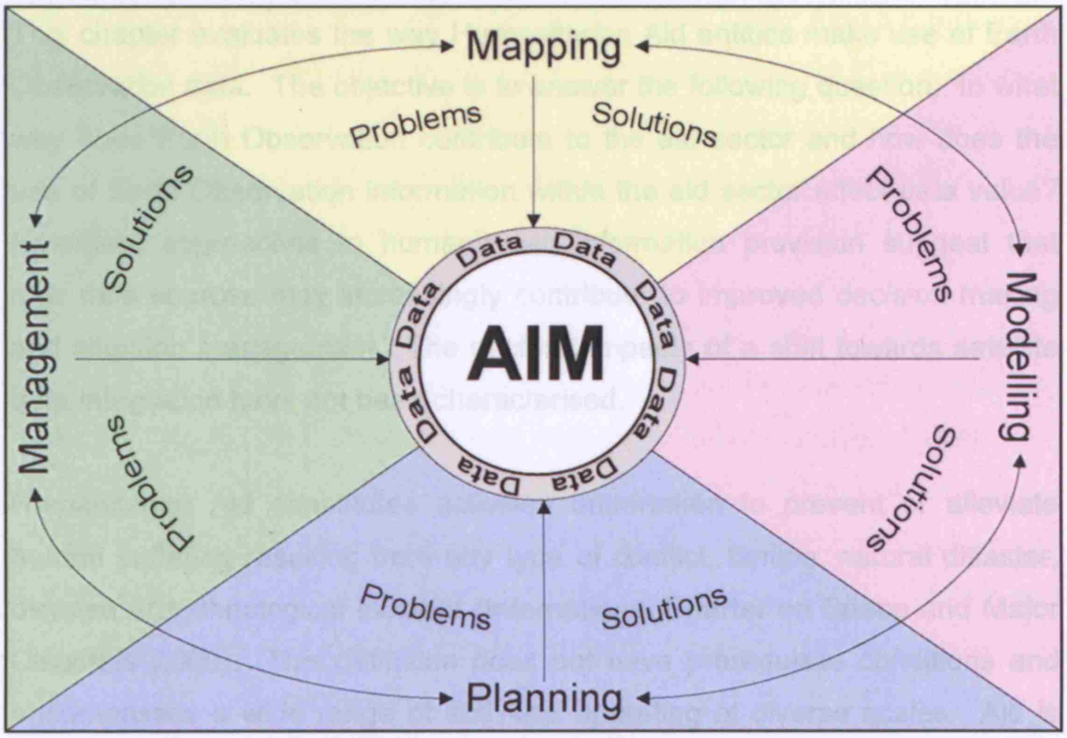

Figure 5.16 Generalised value model, illustrating the requirements of common activities, and an approach for evaluating the extent to which these problems can be addressed using Earth Observation data. In addition, the generalised model illustrates that a single data set can simultaneously address diverse needs within separate user-groups.

Chapter 6 THE VALUE OF EARTH OBSERVATION DATA FOR HUMANITARIAN AID

6.1. The Humanitarian Aid Sector

6.1.1. **Objectives**

6.1.1.1. **Actors in Aid**

This chapter evaluates the way Humanitarian Aid entities make use of Earth Observation data. The objective is to answer the following question: In what way does Earth Observation contribute to the aid sector and how does the use of Earth Observation information within the aid sector affect data value? Emergent approaches to humanitarian information provision suggest that new data sources may increasingly contribute to improved decision making and situation management. The sectoral impacts of a shift towards satellite data integration have not been characterised.

Humanitarian Aid constitutes activities undertaken to prevent or alleviate human suffering resulting from any type of conflict, famine, natural disaster, disease or technological incident (International Charter on Space and Major Disasters 2000). This definition does not have prerequisite conditions and encompasses a wide range of activities operating at diverse scales. Aid is local to global and can be multilateral, bilateral or unilateral. It can be administered through governmental or non-governmental organisations, charities and other not-for-profit entities. Around 26,000 non-governmental humanitarian aid organisations are currently operational; the number has increased from 6,000 in 1992 (Verboom 2002). Messick (2004) outlines problems facing aid workers, and states that humanitarian interventions comprise "every function of service and supply at state and local levels ... such a chaotic environment is complicated because standards and sharing agreements must be constructed from scratch and on-the-fly". In addition, Messick warns that "sometimes people shoot at you or blow up things along the way".

Aid agencies operate at many scales. The top level comprises internationally funded non-governmental organisations (NGOs) and agencies such as World Bank and the United Nations (UN), supported by multilateral governmental funding and recognised in legislature. Below this are international foundations and charities with widespread public support. At lower levels, national and regional agencies exist with specific objectives and ideologies. Donations are used to fund work in specific areas; some Humanitarian Aid entities work within geographical areas, such as Moroccan Red Crescent and African Medical Research Foundation. Some charities work globally but have a specified remit (Action Against Hunger and Landmine Action), and others are general in their approach (CARE International, OXFAM).

Agency operations are diverse in location and scope. Some agencies only operate in the theatre of activity (the 'host' nation), with a skeleton staff in the home nation. A large number of coordinating charities do not employ any staff at the site of the emergency. The deployment of personnel depends entirely on agency remit; a lobbying and strategic entity does not require staff at the site of the humanitarian crisis. But for capacity-building and infrastructure, medical aid or camp management, ground staff are essential. Reports suggest acceptance and integration of local skills and indigenous knowledge is very variable in humanitarian interventions, although the contributions of such knowledge are increasingly recognised (Twigg 2006, personal communication). In humanitarian operations a "pragmatic, all-hands-on-deck attitude" is preferred by recipients, who express little or no preference for operational provider (Minear 2005).

6.1.1.2. **Interventions**

The phrase 'natural disaster' has entered the vernacular of humanitarian assistance and is now widely used. Hurricane Katrina (2005), the Bam earthquake (2003) and the Asian Tsunami (2004) required large scale humanitarian intervention and were extensively covered by global media under headlines reporting 'natural disaster'; a term that is uninformative and misleading (Twigg 2004). Natural events are capable of causing suffering, but without human context they are not disasters as they would cause no harm if they were distant from populations and infrastructure. In this sense, they are only disastrous when combined with human vulnerability. It is more logical to discuss hazards and vulnerability, and to work on the principle that the management of each requires different skills and strategies. To effectively assess vulnerability, independent and credible data must be interpreted by experienced disaster managers in the context of a decision-support network (ODI 2004).

The populations most in need of aid following an event are typically those who were least well-prepared. This link is so clear that aid organisations increasingly recognise the need for hazard preparedness and mitigation activities, alongside assessments of local hazard coping strategies. Poor hazard awareness is the result of several overlapping factors. Education plays an important role as residents may not expect a natural event that has never occurred in their lifetime. The population may be unaware of the most effective response to a hazard. Marginalised populations are also more vulnerable as they are not empowered to make lifestyle choices and must use resources rejected by higher social groups, such as areas most exposed to natural or technological hazards (Twigg 2004).

Aid agencies and policy-makers typically use a top-level distinction of three types of humanitarian emergency. They are natural events, technological accidents and complex emergencies (Zimmerman 1995). 'Natural events' include extreme weather, landslides, mudslides, earthquakes, tsunamis, forest fires, volcanic events and drought; many organisations include outbreaks of disease and infestations. 'Technological accidents' encompasses radioactive, hydrocarbon or toxic chemical spills and explosions. Finally, 'complex emergencies' may involve political unrest and conflict, leading to large-scale civilian displacement, poor food security and escalating risk to public health and welfare through drought, famine, flooding or discrimination. Emergencies which require humanitarian intervention are likely to occur in developing nations, where infrastructure and response systems may be less developed and where accessibility may be limited.

Risk and event categorisation schemes have traditionally been based upon the type of hazard (Dao and Peduzzi 2004, Peduzzi et al. 2005), but several authors note that it is the sequence of events, not the cause, which determines the appropriate remedial and mitigating action. Zimmerman (1995) advocates the use of the terms "sudden-onset" and "complex" emergencies. This scheme of categorisation is compatible with aid organisation management; when interviewed, one worker from an international aid organisation states: "it might sound unkind but we're not interested in the type of event; we need to know what assistance is required, when and by whom" (anonymous 2005).

For evaluating and mapping risk, Dao and Peduzzi (2004) develop themes proposed by the United Nations Development Programme (UNDP) which suggest that socio-economic factors strongly influence vulnerability. When developing nations are subjected to similar hazard events to developed nations, citizens of the developing nations are at greater risk. In the period between 1980 and 2000, 94 per cent of global hazard casualties were the result of four event types: droughts, earthquakes, cyclones and floods. Supporting increased use of monitoring approaches and risk mapping, the models proposed by Dao and Peduzzi (2004), which were parameterised using historic 'disaster' information, suggest that physical exposure to hazardous events composes the largest element of risk. Only in the case of drought was socio-economic development a more significant input. One event classification approach that is gaining acceptance is the Global Identifier scheme, known as GLIDE (www.GlideNumber.net 2006). As a response to the confusing and time-consuming nature of disaster research, it was proposed that each hazard event should be ratified by the Centre for Research on the Epidemiology of Disasters (CRED) at the University of Louvain in Brussels. CRED has operated as a non-profit institution since 1973, with links to the World Health Organisation formed in 1980. The Institution maintains the Emergency and Disasters Database, EM-DAT, which provides complete and verified information on disasters and their human and economic impact, organised by country and event type. Once accredited and added to the global database, the event is allocated a unique code based on the disaster type, year of event, a sequential number and the ISO three-letter country code. For example, LS-2006-07-PNG refers to a landslide (LS) in the year 2006. The event is number 07, and it occurred in Papua New Guinea (PNG). The GLIDE initiative develops key information-sharing themes, and has been supported by the UN Office for the Coordination of Humanitarian Affairs through the ReliefWeb internet site.

6.1.2. Defining Value

In general terms, value is defined as the positive effect attributed to behaviour or materials on the pre-existing situation, moderated by extra problems caused and subject to constraints of cost or practicability. In the context of humanitarian aid, effective use of any data source enhances its worth to the user group which, in turn, increases its value. The value of Earth Observation data for humanitarian aid is demonstrable through user achievements. Value can be attributed whether these activities directly generate revenue or not. In addition to economic value, non-market social value can be captured using a survey of user activities. Social benefit is derived from data when its use increases the scope or efficacy of humanitarian action.

Data has social value if it contributes to the operational capacity of aid agencies and leads to a reduction in human suffering, as discussed in Chapter 4. Societal benefits of this kind are not represented in financial reporting and accounting because they do not contribute to revenue; they are non-market in nature. Services of this kind have been under-represented in the past when compared to market-based economic value.

Allan (1992) states that several impediments to the uptake of Earth Observation data "depress prices so that they can never approach the price which would cover all direct costs, indirect costs, overhead and a profit ... they can be regarded in national accounting terms as an inefficiency which could be accounted as a cost". The two primary inhibitors are that space technology is perceived as a governmental monopoly, and that institutional inertia prevents experimentation and slows the implementation of new approaches. In addition, humanitarian use cannot be exploited as a typical market by data suppliers and value-adding companies because aid agencies often do not have the resources to acquire data at market value. Models of humanitarian data licensing and distribution include means for cooperation and sharing using mechanisms such as Club Good provision (see section 4.2.7.2). Dissemination of information is supported by programmes such as UN Office for the Coordination of Humanitarian Affairs (OCHA) ReliefWeb, Respond and Reuters AlertNet.

Some economic value can be derived from humanitarian information use. When data is used to augment or replace current practices, the cost differential between the old and new approaches can be measured. This leads to a 'replacement value' for the data. What would it cost to go back to the old methods, and what would be the cost implication of re-introduced inefficiencies? This approach is problematic when institutional inertia prevents the adoption of the new methods required for this comparison. Allan (1992) notes that "in order to sharpen awareness of the costs of non-adoption" users will be forced to review all options in the event of technological change, "not just the familiar ones".

6.1.3. Information Requirements in Humanitarian Aid

Every humanitarian aid intervention has location and extent in both spatial and temporal dimensions. This information defines the position and urgency of the situation which influences the type, rapidity and extent of response. Disaster managers and aid professionals need up-to-date, accurate geographic information at varying spatial and temporal scales. Socio-cultural, economic and geospatial data is used by aid workers to plan and coordinate interventions in the immediate aftermath of an event, as well as in medium- and long-term recovery phases.

Recovery operations can be informed by pre-event spatial data, which can be combined with other pre-existing data sources to model movement of people or the damage caused by a natural event. Pre-event information can also guide rescue staff densely-occupied locations such as schools and hospitals where special attention may be required. Bridges or other types of infrastructure that may be difficult or impossible to locate after the event has occurred can be highlighted.

Aid workers require pre-event local information and typically request ongoing data updates during response and recovery activities. The frequency of situation reports determines the temporal resolution of ongoing data collection. It may be impossible to acquire some types of pre-event data; demographic information of internally displaced people for example, is rarely collected before aid is summoned. In these cases field workers use the best available proxy in combination with primary data collection. In the immediate aftermath of an event, the following information is commonly required by humanitarian aid agencies (UN High Commission for Refugees 2005, Beck 2005).

- What are the victims' needs?
- What happened?
- When did the event occur and how severe was it?
- Had there been a risk assessment, and was there a contingency plan?
- Has the hazard passed or is more activity likely?
- What are the human, physical, economic and technological consequences?
- What is the land use and land cover at ground zero?
- What is the demographic of affected people?
- In what way is morale and community spirit affected?
- Has there been a local response, and what was the nature of it?
- Have local services (e.g. water supply and communications) been damaged?
- Is more help on the way?

Emergency aid agencies respond to hazardous events based on experience and the type of suffering expected – for example, they prioritise evacuation infrastructure highly following monsoon-season flooding, and earthquake response requires search and rescue expertise, four-wheel drive vehicles and satellite communications devices. Twigg (2005, personal communication) notes that flexibility in response is important because in humanitarian interventions, priorities change over time, to reflect changing user needs.

6.1.4. Intervention Planning

Basic information is required customise response, ensuring that useful items are despatched to the correct location at the appropriate time (UNHCR 2005). Agencies have historically performed poorly in this respect, and wastage of aid resources has been a problem (Carboni 2004, Beck 2005). 55 per cent of Indian aid recipients following the Asian Tsunami in 2004 felt that clothing they were given was "culturally inappropriate or undignified" (*Health Emergency Management New Zealand* November 2005). Twigg (2005, personal communication) comments that identification of groups and individuals most in need can be a significant challenge, especially if individuals are discriminated against or marginalised within communities. Poorly targeted aid can be wasted. In several cases aid organisations have invested heavily in feedback exercises, and published literature to evaluate retrospectively event response, identify mistakes and poor practice, and recommend change (Pan-American Health Organisation 2006, Disasters Emergency Committee 2001).

Aid entities make complex choices in crisis situations. The outcome of decision-making determines human safety and suffering, so large amounts of pressure and stress rest on emergency managers. Staff training and experience can offset this, but effective response also relies upon well-planned actions within a detailed framework (PAHO 2006). Adherence to predefined guidelines and standard operating procedure removes some personal responsibility from employees. Recognising these issues the Pan-American Health Organisation developed a computerised supply management solution, called SUMA, to support field-based decision making (Poncelet 2006).

6.1.5. **Wastage and Information**

The effects of errors in the decision-making process are far-reaching in part because many charitable agencies may have very limited access to funding (Jones et al. 2004). Governmental support for others introduces the need for third- party audits. Inefficiency and resource wastage jeopardise future funding and reduce available capital for ongoing projects. Potential recipients are most negatively affected by poor aid administration. An illustrative example of a complex-emergency aid intervention follows.

Following conflict in the former states of Yugoslavia throughout the early 1990s, many internally-displaced people were vulnerable to cold weather in the Balkan region. Lomas (aidworkers.net, December 28 2003) comments that the Italian Red Cross donated "a truck load of clothes", which were delivered to aid centres catering for the needs of displaced people and refugees fleeing the civil war. Fighting was not confined to specific regions and sporadic fire-fights between soldiers and dispersed militias and guerrilla fighters occurred throughout the snow-covered countryside. Against this background, displaced civilians attempted to find relatives and protect their belongings. When the aid shipment was opened it was found to contain military surplus uniforms and combat fatigues, which could not be distributed among refugees; they would be at risk of being mistaken for combatants. After a period of storage the unusable clothing was burned to provide warmth and to reduce the risk it posed to humanitarian forces, who could not appear to supply rebel forces or cooperate with military factions.

The initial erroneous supply of clothing led to unnecessary use of communications and transport infrastructure (internal communications within the agency, liaison with the donor area, use of road transportation, containers). This caused wastage in the source nation in terms of unnecessary fuel usage, personnel and environmental cost, and adversely affected rapidity of response to concurrent events. A supply cost for the donation itself was also incurred. In the target area, the donation was transported, unloaded and stored; a waste of staff resources and transport infrastructure. Because the unusable product could not be distributed, storage costs were incurred. For their own safety, non-combatants were prevented from looting from the donation, which meant it was guarded; an additional staffing overhead. In addition the clothing represented a risk to the security of staff and the integrity of the humanitarian contingent. Aid workers were able to retain a small benefit, because burning the inappropriate goods provided a small amount of heat for refugees. In humanitarian aid it is preferable to decline inappropriate donations. For the same reasons, choice of digital data is important; lack of data is better than possession of erroneous or misleading information.

The distribution of aid that remains unused is extremely wasteful. To understand the implications of this problem the economic theory of opportunity cost is useful. The opportunity cost of the inappropriate items sent as aid outweighs the replacement cost of the asset (in this case, the clothing) by up to seven times (Pearce 1993). The clothing is unavailable for other locations and will be wasted by being used as an inefficient fuel. Non-renewable resources and labour have been expended for no benefit transporting the donation to a place where it cannot be used. In addition, the economic cost of the clothing is now invested in a fixed asset, so the funds no longer accrue interest and cannot be used elsewhere.

6.1.6. **Streamlining Aid Through Intelligence**

Wastage can be reduced or eliminated if correct resources are sent to theatres of emergency operations. To accurately assess victim needs it is essential to acquire up to date information covering the affected area. Needs assessment and emergency mapping represent significant and sometimes irreplaceable contributions to humanitarian aid activities that can be made by Earth Observation.

Well-planned expenditure on improved information yields cost savings and reduced wastage. Intelligence-gathering may also lead to enhanced capability. Attitudes are changing in the aid sector, reflecting a growing consensus that "information alone is a form of disaster response", and that in addition to material resources, "accurate timely information can make the difference between life and death" (International Federations of Red Cross and Red Crescent, World Disasters Report 2005).

It is difficult to justify the cost of information expenditure because benefits and cost savings are incident-dependent and highly variable. The nature of the benefit-stream makes commitment to new information sources a short-term risk; initial capital outlay is high and benefits occur downstream. In some cases the optimisation cost of new technology is borne by early-adoption users such as those in academia or government, and aid professionals can obtain trickle-down benefits. It may be possible to recoup all information spending through streamlining operating procedures.

6.1.7. Aid Agencies and Data Collection

6.1.7.1. Procedures

Primary data collection is important in aid, because secondary sources often supply misleading, inconsistent or inaccurate data. In some cases the information is obsolete; Médecins Sans Frontiers report that 1960s Russian maps, labelled with Cyrillic characters, were the best they could find for parts of Afghanistan during recent conflict. Obsolete maps can be a problem when ethnic populations do not recognise colonial names - in Afghanistan, many Russian names have been replaced with local variants, often spelled phonetically. In other cases the deception is deliberate. "A spokeswoman for the FSB [the Russian national security service] confirmed that it controls maps around sites deemed important for national security, including oil fields ... at BP, engineers say the doctored maps [in which a false coordinate system is used, and true North is altered] are a nuisance" reports the *International Herald Tribune* (2005). Russian maps of Syria "have a specific coordinate system and a local false origin that can be difficult to ascertain ... military sites are removed" (Donoghue 2007, personal communication).

In acquiring accurate primary data aid entities face three main problems: the large expense of data collection, the difficulty in obtaining representative coverage in large areas, and the need to rapidly collect and collate data to support decision-making. Issues such as negotiating access, exposure to risk of disease or injury, and cross-cultural communication are secondary to these two inhibitors. The biggest issue facing users of secondary data is that of provenance; how can users ascertain the independence and quality of data?

Aid agencies use large numbers of field staff to collect unbiased primary data that reflects the situation on the ground; 92 per cent of World Food Programme food security staff work in the field as National Officers, UN volunteers, general service staff or retained contractors (WFP 2005). This data is used to inform workers, to raise the profile of events, and to apply pressure to government. Although very expensive and time-consuming, independently collected data maintains an audit trail and enables monitoring of provenance and integrity.

Surveys, interviews and focus groups are used to collect qualitative data about historical events, health, recent changes and the morale of affected people. This information assists field staff in decision-making (Twigg, 2004). In addition to socio-economic measures, high quality quantitative information facilitates detailed planning. GPS surveying, soil analysis and water quality testing are typical of the quantitative variables gathered. Localised data collection is conducted in zones of vulnerability or increased human stress, so-called countries of concern as identified by units such as the World Food Programme early warning team and USAID Famine Early Warning System (Arach 2005, personal communication, www.fews.net). A typical FEWS fused information and briefing product, depicting food security, is shown Figure 6.1. Broad area-coverage remotely-sensed data is used alongside *in-situ* sources; USAID maintains a large number of staff as indicated by icons on Figure 6.1. In this area the needs of disaster managers overlap significantly with development agencies or capacity-building missions, so data are often shared. New support agencies such as MapAction assist charitable organisations and NGOs in the collection of geospatial information which requires specialised skills and equipment.

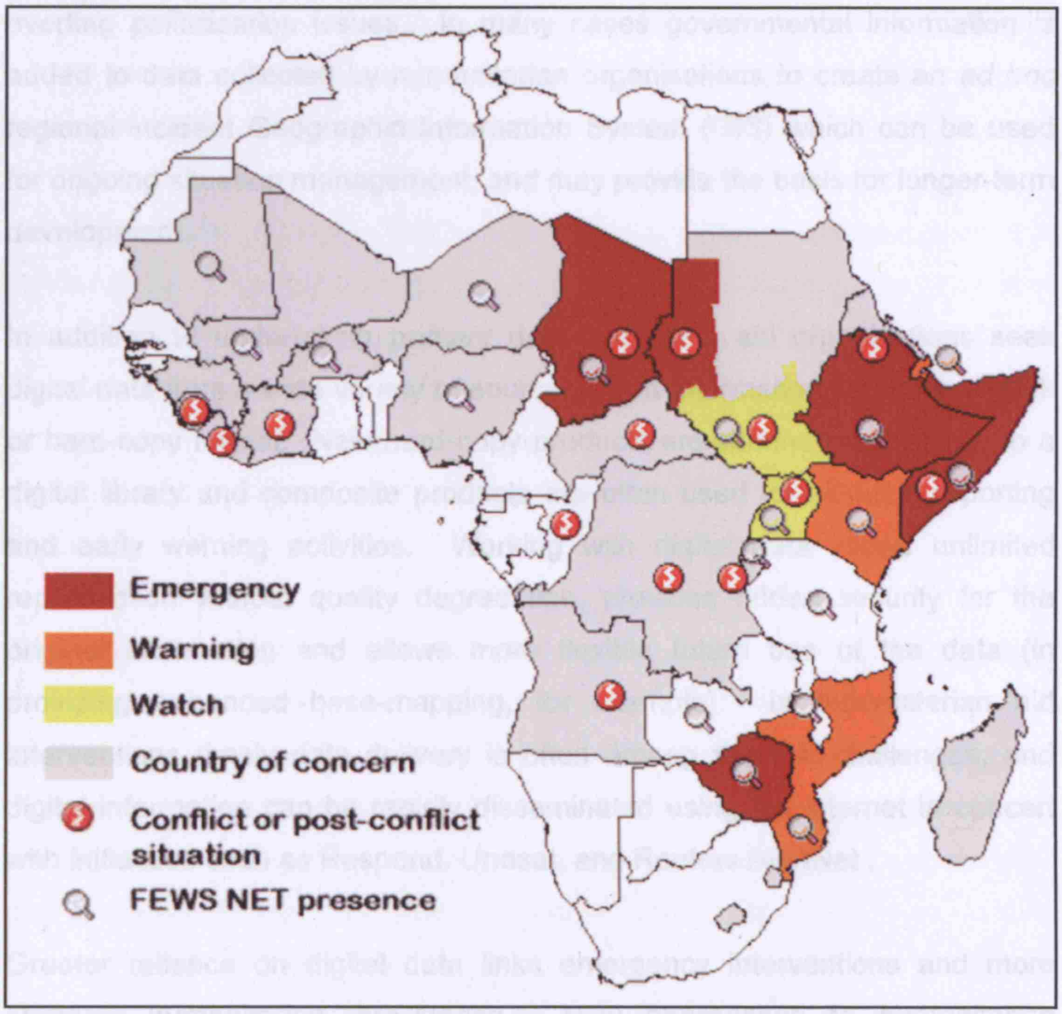

Figure 6.1 Food security alerts for the period November / December 2007. Such fused products are the result of *in-situ* reporting of population status and location, combined with meteorological modelling and remotely sensed parameters (such as NDVI from AVHRR and rainfall estimation from Meteosat). Note the extensive FEWS NET presence. Source: www.fews.net

Governments in affected areas can facilitate activities by providing information and logistical assistance. In areas where natural hazards are the primary focus this is commonly the case. Centralised support is helpful when events and vulnerability cross international borders, as is the case for locustprone or malarial zones (UN ref A/AC.105/828, 105/836 2004, Despland et al. 2004, Zha et al. 2005). Central management from a regional centre can assist in the management of trans-boundary humanitarian intervention by averting politicisation issues. In many cases governmental information is added to data collected by humanitarian organisations to create an *ad hoc* regional incident Geographic Information System (GIS) which can be used for ongoing situation management, and may provide the basis for longer-term development.

In addition to undertaking primary data collection, aid organisations seek digital data from a wide variety of sources. Geo-information can be in digital- or hard-copy format. New hard-copy products are scanned and added to a digital library and composite products are often used for situation reporting and early warning activities. Working with digital data allows unlimited reproduction without quality degradation, provides added security for the original information and allows more flexible future use of the data (in providing enhanced base-mapping, for example). In humanitarian aid interventions timely data delivery is often among the first challenges, and digital information can be rapidly disseminated using the internet in concert with initiatives such as Respond, Unosat, and Reuters AlertNet .

Greater reliance on digital data links emergency interventions and more strategic humanitarian intelligence. New approaches to humanitarian information collection can be verified and validated through peer-reviewed scientific literature, assuring quality, reliability and applicability. Referring to humanitarian satellite data, Funk and Brown (2006) state that "the enhanced integration of remotely sensed vegetation and precipitation products has an immediate and interested audience, with the ability to inform policy and emergency response agencies and governments".

6.1.7.2. **Case Study: Monitoring Locusts**

To take the example of locust infestation, the last thirty years has seen a shift from ground-based response and mitigation activities to preventative and predictive approaches supported by remote sensing. International agencies such as FAO have adopted principles of Earth Observation and integrated them with operations in candidate nations. Cherlet et al. (2004) state that "ensuring food security through technology transfer ...to increase food production can only be at its maximum efficiency when safekeeping of existing food crops is well established. [FAO] protection against migrant pests plays a crucial role in this process".

The acquisition of timely locust data using *in situ* measurements is a challenge for three reasons. Firstly, locust breeding concentrations are often discrete and dispersed over large areas; in summer 2002, 1.47 million ha of land in 160 countries was affected by locust outbreaks (Zha et al. 2005). Swarms can travel 4,000km between breeding events, and can reach densities of 6,000 heads per square metre (Despland et al. 2004, Zha et al. 2005).

Secondly, the breeding cycle of most locusts only takes 2-3 months and includes nymph stages where no tangible damage to vegetation is present. Only late-stage individuals leave signature vegetation damage. Finally, certain conditions must be met for swarming to occur. If high population density is reached during breeding cycles, green solitarious locusts change phase and become patterned gregarious types, which tend to swarm (Despland et al. 2004). The density of population s related to the number of individuals and the spatial extent of food resources. If resources are abundant, large numbers of locusts rapidly reproduce. A sudden increase in feeding locusts exhausts local resources and reduces available habitat. This leads to concentration of populations in remaining patches of vegetation and brings about the phase change which precludes outbreak. The temporal and spatial dispersal of locust-related phenomena considerably limits the window of opportunity for successful detection and mapping (Despland et al. 2004).

Remote sensing data has been used to map and monitor locust outbreak zones since the early 1970s, and large-scale detection and intervention programmes are managed by agencies including the Food and Agriculture Organisation (FAO) and the Australian Plague Locust Commission (APLC).

Additionally, a pilot programme has begun in China with the aim of increasing the efficiency of locust monitoring. The study, which used Landsat ETM+ data, reported a 95% detection rate for locust-affected Eastern Chinese shallow water basins (Ma et al. 2005). Ceccato (2004) states that within the FAO locust monitoring programme "satellite images (SPOT-Vegetation[1] and Terra MODIS) are now used operationally by some locust survey teams to direct their surveys toward high-risk regions and allow them to optimise use of available resources". Breeding grounds are distributed throughout large and inaccessible regions, so remote sensing has permitted the more focused application of personnel and finances.

> [In humanitarian early warning] the use of remotely sensed imagery is still far from routine. Delays in uptake have been attributed to the perceived costs of image processing equipment and expertise, lack of access to imagery and the novelty of the techniques. These factors need no longer be viewed as substantial constraints. Very sophisticated analyses can now be performed on relatively modestly priced computer systems... Perhaps most importantly, satellite-sensor data have become more widely and freely available, especially to research workers in developing countries (Hay et al. 1998).

Locust monitoring is not the only success: Earth Observation has been applied in other areas of humanitarian early warning, including drought and crop failure (FEWS), crop yield estimation (de Wit and van Diepen 2007), malarial mosquito monitoring (Hay et al. 1998), and Rift Valley Fever prediction (Linthicum et al. 1999, cited by Funk and Brown 2006). As development organisations work geospatial data of improved quality and increased quantity, new challenges emerge in the fields of data management, delivery and dissemination.

6.1.7.3. **Management, Delivery and Dissemination**

In some cases the agency is not custodian of the data. Third-party dissemination of collated data products is possible via the Internet, as exemplified by the OCHA ReliefWeb and the Reuters AlertNet system

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[1] Before 1998, NOAA AVHRR data was used for vegetation monitoring. Since then, an EU / JRC-FAO agreement has provided dekadal imagery free of charge (Cherlet et al. 2004)

(OCHA, Reuters, 2006). Registered users can download maps, diagrams, satellite images and situation reports. Other humanitarian programmes also distribute data directly (UN, UNOSAT, Respond, BBC). In contrast to sectors more widely exposed to commercial market development, aid entities openly share data. For this reason, hard-copy information may be digitised or collated by one organisation, but it may be used by several more.

Even in the presence of operational digital mapping solutions "any credible mapping service will still need to be based around delivering paper maps to the field" (Jones et al. 2002). For hard-copy data dissemination, two primary approaches are used. In cases where technical infrastructure is poorly developed or has been destroyed, data products are printed in the originating nation and shipped to the area of interest alongside other humanitarian supplies. However, if sufficient capacity exists it may be more appropriate to employ local expertise. This enables more rapid dissemination of updated products and the inclusion of local knowledge in later product iterations. Translating place names into dialect has been identified as a simple but useful value-adding step (*GeoSpace International* 2006), especially in areas where anglicised spelling of local names changes their pronunciation beyond recognition (Yassinov, personal communication, 2004). Both approaches are employed by UN Humanitarian Information Centres.

The charity MapAction work to overcome the "last mile" problem, aiming to resolve difficulties encountered distributing geospatial products generated for humanitarian purposes (Bradly and Irving, personal communication 2006). Prih Harjadi of the Indonesian Meteorological and Geophysical Agency (IMGA) states that "we could produce information [about the Asian tsunami] but we would just send it to local governments ... there is nothing to link the last mile" to those users in the field who would benefit (*TelecomAsia* 2006).

Poor access to technology can preclude the use of digital data. Even when technology is available, many high-technology solutions remain inappropriate in the field due to their reliance on relatively fragile and costly equipment. Although aid agencies and hardware vendors are working together to produce rugged and scalable methods of delivering bandwidth to aid workers (such as the Net.Relief.Kit from NetHope.org), there are currently no industry standards for such systems or evidence of widespread applications.

Mitchell (personal communication, 2006) states that there is little value in employing hard- and software solutions if they are so complex that a "chauffeur is required to drive" them; information technology is a hindrance to those who are not literate in it. Institutional inertia also makes aid agencies reticent to try new approaches; there "is a particular sensitivity to the use of electronic equipment in the field ... staff worry that their operatives will be spending all their time trying to get computer and communications equipment working, rather than relying on tried and tested techniques" (Jones et al. 2004). In post-conflict or post-emergency areas, robust solutions cannot be predicated upon high technology: Messick (2004) states "little attention [is] paid to local support capabilities or the organisational changes in policies, staffing and business processes [that are] required to actually use and maintain the systems".

A hybrid approach enables specialised off-site processing of detailed base-map data, allied to updating and printing in the field. Large-scale distribution of hard-copy map products is facilitated by rapid printing; the UN Humanitarian Information Centre in Banda Aceh (Indonesia) printed and distributed 5,000 satellite map sheets within days of the 2004 Asian tsunami. The maps have been rapidly integrated into local planning procedure, and users report that satellite maps showing simulated true-colour are more intuitively useful than those annotated with foreign mapping conventions and symbols (Irving, personal communication, 2006).

In terms of development and capacity-building, high quality mapping has proven an excellent starting point. Tsunami inundation maps published by the UN Humanitarian Information Centre using IKONOS data have become a valuable commodity in Sri Lanka and Indonesia, where civilians have historically had limited access to mapping. A thriving secondary market has rapidly developed, indicating the value local residents find in the maps.

6.1.8. Limitations of Data Collection

In many aid interventions it is impossible to secure the support of the host government. Furthermore, in times of conflict and complex emergencies there may be no government in place. Political objectives can delay admission that there is a problem, as in Zimbabwe and Sudan (Amnesty International UK 2004, US Agency for International Development 2005). Cultural issues can hinder access to information or may result in unacceptable discrepancies in information coverage, as in Pakistan and Kashmir (Amnesty International UK 2005). Socio-cultural issues compound inadequacies or problems in pre-existing data: in zones of political instability it can be impossible to secure access to people and settlements, and governments may block the dissemination of accurate geographical information if images depict militarised zones or disputed frontiers. Challenges are present even outside emergencies. On a strategic level, "food insecurity typically results from climate events and societal vulnerabilities, [so] crises almost always arise in areas with limited *in situ* data...[and] satellite information is thus the first line of defence" (Funk and Brown 2006).

Following a severe earthquake in Kashmir on 8 October 2005, the International Charter for Space and Major Disasters (ICSMD, introduced in section 4.3.1.8) was invoked by the Indian Space Research Organisation to rapidly supply satellite data at very high spatial resolution. Aid agencies and third-parties, such as Reuters AlertNet, welcomed Charter data and prepared to use images to locate landslides and map surviving transport links. However, on 10 October 2005 all images of the region were removed from UN websites following a meeting which reportedly "discussed an official reminder from Pakistan about the political sensitivity of the area ... Pakistan and India have long fought over Kashmir, and there were concerns that pictures could compromise security" (*Nature*, 17 October 2005). Although Pakistan firmly denied requesting the removal of data, a week elapsed before the geospatial information was reinstated. On 18 October 2005 the UN sent a memo advising that the decision had been reversed and bans on images had been lifted. An anonymous official from the EU Responses to Disasters and Emergencies Centre was quoted in the journal *Nature*: "the [humanitarian] community has been starved of pertinent, up-to-date information on remote inaccessible areas" (*Nature*, 17 October 2005) Mark Jones, programme director of Reuters AlertNet added that "getting aid to the affected communities has been extraordinarily difficult; many of them aren't marked on available maps" (Jones, personal communication, 2006).

Humanitarian organisations communicate with leaders in areas of concern to negotiate access. Services such as World Food Programme Early Warning System currently list 80 countries of concern, where intervention is required. However, in some areas of conflict foreign nationals have been excluded - such as during the early stages of the 2005 Darfur crisis in Sudan. In this case severe emergencies can develop in the period before an international state of emergency is declared or UN Security Council measures are taken. Primary field data collection can only resume when international peacekeepers or observers are installed.

Several options are open to aid workers in circumstances where no primary field data collection is possible, such as ongoing conflict or the breakdown of international diplomacy. When preparing to deploy in a region, humanitarian organisations use the following resources.

- Pre-existing maps (e.g. Tactical Pilotage Charts)
- Digital resources (e.g. CIA Fact Book, Ordnance Survey, VMAP0)
- Data from previous interventions
- Information from humanitarian network resources
- News agency reporting
- Aerial / Satellite Data, (new acquisitions and pre-event archive data)

6.2. *Use of Earth Observation Data in the Aid Sector*

6.2.1. **Background**

In addition to international agreements such as the International Charter for Space and Major Disasters (introduced in section 4.3.1.8), three main initiatives facilitate the link between Earth Observation data and users within the aid sector: Respond, Unosat and Reuters AlertNet. Despite overlapping aims, each programme is administered by a separate entity. At the top level Reuters AlertNet and Unosat are contributing partners to the Respond initiative as in-sector providers. Each programme maintains activities outside the Respond remit. In many instances there is convergence of objectives and collaboration; all programmes work towards providing a valuable service without a voiced concept of 'market share'. Yet there is a tacit need to be the most useful service by adding value. Reuters AlertNet combines images with a map server and numerous news feeds, Unosat specialises in rapid response (often working as a supplier for ICSMD activations) and hosts a user-community, and Respond brings together a broad and deep array of experienced partners.

The funding streams that support each initiative are different. Respond, funded by the European Space Agency as part of the Global Monitoring of Environment and Security (GMES) initiative, functions as a testing environment for new services which can be delivered using Earth Observation technology. ESA states that projects like Respond "enable end-users to become involved in 'closing the loop' between operational results ... and the definition of new systems" (ESA 2006).

Unosat is an inter-agency programme that was founded to assist UN agencies in acquiring and using Earth Observation data for humanitarian purposes, with a secondary aim of providing training and geospatial capacity-building to developing nations (Bjorgo 2005). Disasters are disruptive to international development, and their effective mitigation protects investment from developed nations.

Reuters AlertNet arose through a charitable foundation linked to the global news agency Reuters, based in London. Having documented poor inter-agency communication and a deficiency of useful shared information during the Rwandan conflict of the 1990s, staff applied skills through news dissemination to geospatial (and other) types of humanitarian data.

6.2.2. **Respond**

One of the key initiatives of the European Space Agency (ESA) is called GMES. As part of the initial phase of GMES, 10 test implementations (GMES Service Elements, or GSEs) have been developed to cover diverse themes. Respond is the title for the GSE responsible for the development and assistance of the humanitarian community. The Respond Consortium functions as a network with five tiers, administered by the top-level prime contractor, Infoterra UK Ltd (shown Figure 6.2). At the next level are in-sector providers, assigned the role of supplying geographic information to the humanitarian community. They are the European Commission Joint Research Centre (EC JRC), Reuters AlertNet, Unosat and DLR (the German national space agency - Deutsches Zentrum für Luft-und Raumfahrt). On the third tier reside the five entities responsible for processing geospatial data, known as value-adding companies. They are Metria (Sweden), Keyobs (Belgium), SERTIT (France), Infoterra (UK) and MapAction (UK). On the fourth tier the consortium is supported by six partners: Kayser-Threde and Controlware from Germany, SciSys, Surrey Satellite Technology Ltd, ESYS and the British National Space Centre from the UK. Finally, core users reside on the fifth tier. They are the UN Office for the Coordination of Humanitarian Affairs (OCHA), United Nations Office for Project Services (UNOPS), the office of the International Strategy for Disaster Reduction (ISDR), the German Red Cross (DRK) and the German Governmental Disaster Relief Organisation (THW).

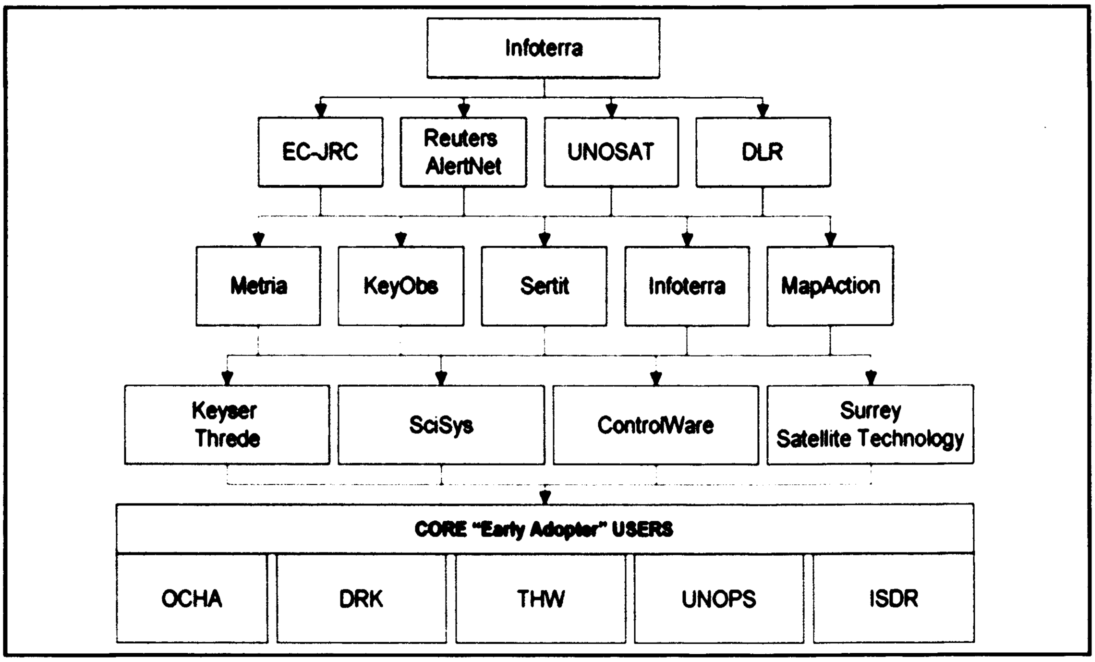

Figure 6.2 The five-tier organisation of the Respond Consortium.

Infoterra state that Respond "will strive to increase the efficiency and effectiveness of the European and international humanitarian community through the appropriate and reliable application of geographical information" (Infoterra UK, 2005). In the initial scoping phase, Respond aimed to answer the following questions in the context of humanitarian aid.

- What information is needed?
- What services can be provided?
- What are the benefits for Europe's citizens?
- Do the benefits justify the costs?

Outside the core programme objectives the aim of Respond is to provide a conduit for the simple and timely supply of maps, images and other geo-information. Veck (personal communication, 2005) states that "in the diverse culture of aid, the recipients of Respond products are completely uninterested in satellites", an impression confirmed by ESA (2006): "while there is a real requirement for geographic information, these users have little or no interest in satellites, raw imagery or processing methods". Several years before the creation of Respond, Stephenson and Anderson (1997) assert that "the next wave of IT development [in aid] will focus on the delivery of information and experience on-demand, in the right form, at the right time, at the right price" – Respond represents an implementation of this developmental theme.

The "diverse family of charities, international agencies and government institutions" included in the Respond programme receive processed data that is designed to be user-friendly (ESA 2006). Seven services can be provided by Respond:

- Digital and Paper base-maps created using satellite and vector data
- Crisis and Damage mapping
- Situation maps
- Refugee monitoring maps for camp planning and management
- Thematic maps incorporating resilience, health and environmental impact
- Communication and Reporting, including a Forgotten Crises product
- User Alert Services, including hazard forecasting

Other data is produced alongside these products, and Respond "will aim to provide guaranteed access to global mapping, access to an archive of detailed base mapping and rapid assessment maps of major crises" (Infoterra UK 2005).

The primary focus of Respond is serving a user-group composed of European and international aid agencies and other NGOs providing services in the humanitarian sector outside Europe, shown Figure 6.2. Subscribed entities may also engage in other related activities such as peace-keeping, international development and disaster reduction. In addition, products are exploited throughout the UN network of organisations, including OCHA, UNOPS and ISDR.

Initial feedback from the first phase of Respond has been positive. ESA state that "of the 32 service delivery reports [received in the initial 10 months of the project], 29 describe Respond products as "a key input", "very useful" or "useful" ... and the project consortium received a large amount of positive informal feedback" (ESA 2006). User testimonials confirm the usefulness of the data for planning staff evacuations, "saving expensive helicopter time and keeping us working" and state that "until then, we had no map of the operational area whatsoever!" (THW and DRK, cited by ESA 2006).

6.2.3. **Unosat**

Unosat is a UN programme which provides satellite geodata to the aid sector, in addition to providing geographic information systems training and support. The programme began in 2001 with the support of ESA, the French Centre Nationale d'Etudes Spatiales (CNES), the European Organisation of Particle Physics (CERN) and the French and Norwegian Ministries of Foreign Affairs.

Although many Unosat products are delivered via Respond, the programme also operates stand-alone services and distributes International Charter for Space and Major Disasters (ICSMD) activation products. Unlike Respond, Unosat is not an entirely free service for the humanitarian community; many products are chargeable, and the Unosat business model incorporates market development objectives. However, the service is administered under UNOPS guidelines for business best-practice, and aims to supply "low-cost and high quality solutions" (Bjorgo, 2005). The implications of the UN business model are that Unosat is initially a not-for-profit entity that must cover costs.

The Unosat service is administered by the United Nations Institute for Training and Research (UNITAR) and executed by the United Nations Office for Project Services (UNOPS), with assistance from UN field teams. Technical support for the service is provided by CNES and CERN and the team includes database programmers and internet communications specialists (Unosat 2006).

Unosat is funded in three ways depending on the recipient and purpose of the data. ESA GMES funding streams can be used when data is processed under the Respond programme. Data can also be acquired under the terms of the International Charter for Space and Major Disasters when charter activation is requested through the UN Office for Outer Space Affairs (UN OOSA), and data are provided by the one or more of the nine affiliated Space Agencies. In circumstances where neither Respond nor ICSMD is able to fulfil requests, users are obliged to pay for data at the marginal cost price. Data searches and advisory services are free of charge.

Unosat aims to make satellite images and other types of geographic information readily available to aid workers by responding to user needs with "suitable, tailored solutions" (Unosat 2006). The programme aims to end the dominance of purely scientific users by exposing new disciplines to processed images. The initiative aims to "expand direct access to satellite imagery through the internet and other multimedia tools" (Unosat 2006). The remit of Unosat is more extensive than Respond; activities outside core humanitarian action, such as environmental rehabilitation and risk management are included. Unosat is designed to expose "thousands of people around the world, working in the development field, [who] are still using pen and paper to produce resource and risk maps" to the benefits of satellite data (Bjorgo 2005). Unosat provides the following services.

- Raw satellite data (SPOT, SPOT Vegetation, Envisat, Landsat, IKONOS, Quickbird, IRS, Radarsat, ERS, KVR, Orbimage)
- Processed data for specific areas showing land use and land cover, road networks, settlements, hydrology and change detection
- Technical assistance in the production of detailed maps to show damage evaluation and risk mapping (e.g. fire, flood, avalanche, landslide, erosion) as well as assistance in establishing local Geographic Information Centres
- Training to acquire and manage up-to-date geographic information.

These data are typically distributed through the internet; additional ad-hoc training is provided by UNITAR for local authorities and project field personnel, both on the ground and through online courses (providing guides to map interpretation and the application of satellite data). Course units are also available for download through the Unosat website.

Aid workers involved with satellite data can join an online community via the Unosat website. Registered users are able to preview Unosat images and communicate within the forums, but cannot order images via the website. Users must be part of an active member organisation to be eligible for 'active' status and "organisations must be part of a UN initiative or be contracted to work in line with UN policies" (Unosat 2006).

In July 2004 UNHCR field officers in Chad became concerned about the large numbers of Internally Displaced People arriving at refugee camps already holding up to 180,000 individuals. UNHCR stated that "lack of adequate water was the greatest constraint to operations" and that in eastern Chad there was a developing "dire water shortage" (Pagonis, UNHCR 2004). Unosat was deployed with consultants Radar Technologies France to conduct a sub-surface water resource survey of 2,500km^2 to locate hidden desert water resources. The survey used Shuttle Radar Topography Mission (SRTM) digital terrain models, multi-temporal L-band JERS-1 and single-date C-band ERS-1 radar data alongside Landsat ETM+ optical data to investigate the presence of subsurface water. Using appropriate data sources, "it [was] possible to double the success rate of water exploration" (Gachet 2005). Earth Observation data was used to update geological mapping and to provide fused humanitarian intelligence products which informed drilling teams regarding the location of untapped underground water resources (Verjee and Gachet 2006). In this way, more effective staff deployment and greater drinking water provision was directly attributable to the use of satellite-derived data. Aid professionals and UNHCR commented on the success of the mission; "this is a promising example of how space technologies can have a practical and critical role in humanitarian assistance and international development" states Verjee (2004). UNHCR comment that the technique "saved a lot of time and energy searching for water", which is heavily rationed and has been a source of conflict between camp residents (Sanders 2004).

Using radar anomaly maps (such as Figure 6.3), the position of seven planned camps for refugees and displaced person was altered to maximise access to water, transport infrastructure and suitable topography (ESA 2004). Integrating the paper maps with current approaches was a vital step. Local field teams “are not familiar with Earth Observation, but actually proved very interested in the technique” explained Olivier Senegas of the Unosat team (2004).

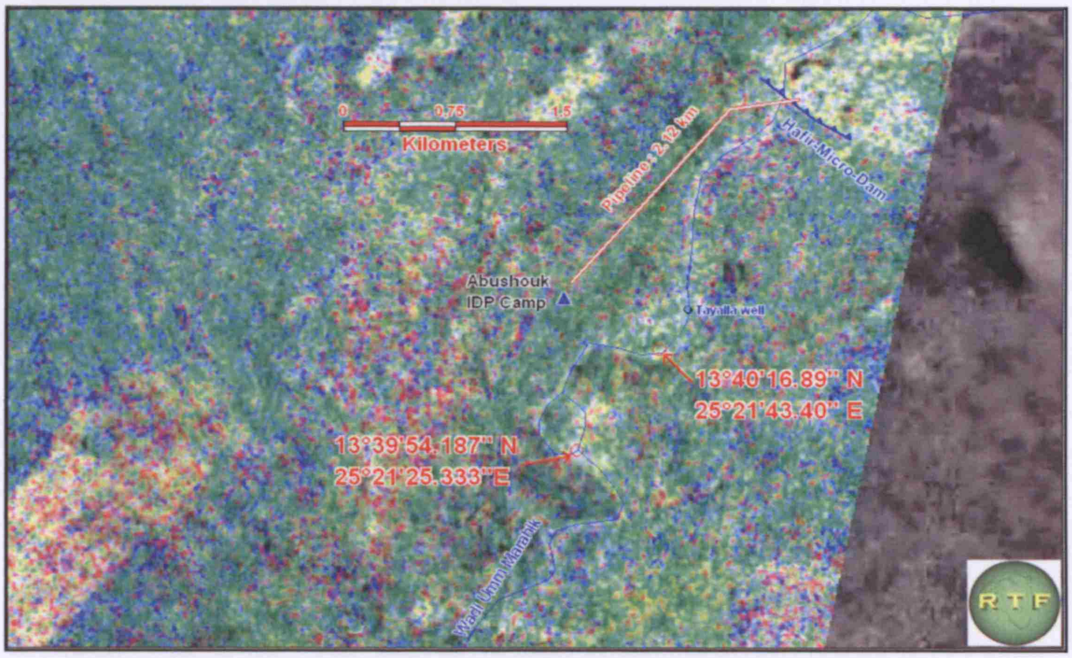

Figure 6.3 Radar image created by Gachet (2005) using L- and C-band radar from JERS-1 and ERS-1 spaceborne sensors, with SRTM terrain data. The image was used to detect subsurface water in Darfur, Sudan (Gachet 2005).

6.2.4. Reuters AlertNet

Reuters AlertNet is an online information service that allows data sharing within the aid community. News, images, maps and other information are collated and distributed via the internet using “Reuters' core skills of speed, accuracy and freedom from bias” (Reuters, 2005). The service is not designed to facilitate the use of satellite data within the aid community, and has no tie to satellite data providers or Space Agencies. Some satellite data (largely Respond products) are distributed through this channel, and the data is recognised by Reuters AlertNet as a useful geographical resource.

Subscribers can upload data directly for rapid distribution and access. In addition to user submissions Reuters AlertNet provide value-added information such as feeds from other news sources, satellite images, background information and maps. The emphasis of the service is on short-term emergency information; the Reuters AlertNet site is not designed to assist with longer-term development goals, in line with the original strengths of the news agency - "handling fast-moving information" and publishing it online.

Reuters AlertNet was initiated by the Reuters Foundation, a charitable trust associated with the Reuters News Agency. The project began in 1997, following an investigation of the aid sector prompted by confusion during the Rwanda crisis in 1994. Trustees of the Reuters Foundation noted that the Agency could assist humanitarian workers for a variety of reasons including the capability to produce and distribute news globally, a world-wide reputation for independence and "an ability to create networks of contributors" (Reuters 2006). The Reuters AlertNet service is run by a dedicated team working from the London offices of Reuters.

The central objective of the Foundation is to undertake sustainable philanthropic and humanitarian work including education, communication and technology projects. None of the services of Reuters AlertNet are chargeable to users. Some service components are sponsored; the European Space Agency provides limited satellite data free of charge and ESRI provide online mapping via the website.

A 1994 Reuters survey of humanitarian data sources concluded that there were shortfalls in three main areas; provision of timely information to charities, sharing of information between charities and the low profile of humanitarian assistance among the general public. By maintaining a website (visited by 60,000 people per day) and an email newsletter, Reuters draws public attention to humanitarian emergencies that are not always reported in the general media. 53 per cent of Reuters AlertNet newsletter subscribers comprise the general public, 42 per cent are relief professionals and 5 per cent are journalists (Reuters 2005).

Based on website statistics provided by Reuters in July 2004, the breakdown of data provided by AlertNet indicates that news feeds (32 per cent), member content (18 per cent) and country profiles (14 per cent) dominate the site in terms of data volume. Images, including photographs, account for 4 per cent of data. Reviewing data volumes it is clear that the site is tailored to provide news, member support and information about countries of concern. Online mapping and country profiles occupy around 14 per cent of Reuters AlertNet. Closer investigation of the website statistics reveals the importance of Earth Observation data sources. Although satellite images and photographs occupy around 4 per cent of the total data space, satellite image downloads represent up to 10 per cent of site traffic. This disproportionately high amount is indicative of a high demand for the small numbers of images served (Shaw, personal communication, 2005).

Map products (which are combined with Country Profiles in the statistics) are also an important product for Reuters AlertNet members, who work in environments where mapping is scarce, expensive and often inaccurate. Mark Jones, editor of the AlertNet programme, explains that "we have the sense that maps are hard to obtain for many areas. We have noticed that even the locator maps of emergency sites produced by Reuters are popular with visitors. In June [2003] our graphic of the Iranian earthquake area was the most retrieved story on the AlertNet site" (Jones et al. 2004).

To become a member of Reuters AlertNet an organisation must be actively involved in humanitarian action, be non-profit and non-discriminatory. New applications are not currently accepted; the programme aims to deepen relationships with the existing 390 members, who work in 90 countries. Reuters AlertNet includes a current member directory which holds contact information, website links, current activities and areas of expertise.

Member organisations have access to areas of the website that are not visible to the general public, which include live Reuters news feeds and items submitted by other members. Users can also subscribe to keyword-based "emergency alerts" to receive targeted news by email. Reuters AlertNet is unique in the method used to acquire data from member organisations. A form-based submission page can be completed by a member, which is very rapidly assimilated into the website. This conduit for users to submit breaking news ensures that the site is, in a sense, constructed by and for the aid community. For the dissemination of geospatial information, maps are hosted by Reuters, but full-resolution images are often served from the Unosat website.

6.2.5. Relationships with Data Providers

The makeup of the formal international humanitarian sector is very different from forestry, for example, as it is dominated by international entities and large non-governmental organisations. Entities rarely compete and many are non-profit, although there is competition for funding. Most agencies in the humanitarian sector cooperate and share common or complementary objectives. The atypical landscape of the humanitarian sector led to the development of an unusual information-supply structure.

Information vendors have been unable to penetrate this market for two main reasons. The first is that most information resellers distribute data acquired using public-sector infrastructure, commonly operated by intergovernmental agencies. The funding governments aim to provide international aid and disaster assistance, so data is provided free of charge to aid agencies through programmes and legislature, eliminating the need for purchase. Even when data is commercial, as in the case of very high resolution sensors such as Quickbird and IKONOS, international funding and special licence provisions are now in place to ensure that almost all data is made available to aid organisations in times of crisis, through the mechanisms discussed here, through governmental provision or by sponsored purchase. In the majority of cases, aid agencies cannot access original data, but compressed image-map products are distributed.

The second reason the market has failed in the humanitarian sector is one of profitability. For a value-adding companies to be profitable, investment of time and expertise must be chargeable. Licensing also influences ongoing profitability and resale value. Aid professionals cannot justify the high cost of this kind of data; in other sectors, its use is routine. Petrochemical exploration, for example, yields such high capital returns that expenditure on data can be many times greater than aid budgets allow. Private sector operators are less concerned with restrictive licence terms, allowing value-adding companies to protect their data even after sale. Faced with the choice of which sector to serve through data production, product development and delivery, value-adding companies choose the most profitable route. For this reason the value-adding sector is poorly developed for humanitarian purposes. Aid agencies have chosen not to enter the commercial data market for two main reasons: budgetary constraints, and the feeling that Earth Observation data should be free of charge when it is used in support of humanitarian work.

Without a well-developed private sector for the processing and supply of information, a diverse range of strategies is employed by humanitarian actors to acquire it. Previous research identifies the creativity and inventiveness that has been required to overcome "data drought" (Jones et al. 2004).

6.3. The Value of Geospatial Information in the Aid Community

A questionnaire is used to characterise the relationship between aid workers and geospatial information. The benefit-streams from data use are clarified and evaluated. This information allows an assessment of the amount of overall value that humanitarian uses of Earth Observation provide. The first part of this chapter characterised humanitarian aid activities and data requirements. The second part introduced programmes which aim to supply appropriate data to humanitarian aid entities, in order to support and augment their capabilities. Following a case study conducted in the forestry sector (Chapter 5) a general model of value has been proposed, shown Figure 5.16. The following survey contributes to an assessment of model applicability in a sector that is influenced by very different developmental objectives. So far, limited user feedback has strongly supported the continuation of this type of data supply (Reuters AlertNet, Respond). This section presents new data, acquired through a survey of humanitarian aid personnel.

6.3.1. Aims

The survey has the following objectives.

- Identify how Earth Observation data is used in humanitarian activities
- Discuss the relationship between traditional and new approaches
- Discover recurrent inhibiting factors
- Evaluate end-user solutions that are employed to overcome problems
- Characterise information requirements (the 'perfect' data)
- Evaluate requirements for timely data and revisit frequency
- Establish whether so-called 'data drought' impairs capability
- Assess the market penetration of several data-provision programmes
- Appraise the usefulness of pre-event catalogued digital satellite data

It is essential to sample the ways in which data is exploited for humanitarian purposes accurately and independently. The relationship between aid professionals and data is explored using twelve open and six multiple-choice questions. No survey of aid workers and geospatial data has been published, although some other work has involved interaction with the aid community (Reuters 1994, Jones et al. 2004, UN Action Team 7 2004).

The questionnaire queried the professional capacity of respondents and the extent to which they had been exposed to Earth Observation data. The relationship between users and data was evaluated. Other information sources that were used were surveyed, and correspondents were asked to identify the "most vital" data, to allow comparisons to be made. A detailed discussion of survey design, dissemination strategy and questions follows.

6.3.2. **Questionnaire Structure**

6.3.2.1. **Design**

General principles of questionnaire design, which were discussed in relation to the forestry survey (Section 5.4), remain relevant for humanitarian aid questionnaires. Broad questionnaire structure remains the same but organisation, layout and dissemination strategy are altered slightly to reflect changes in research focus, amendments and sector-specific problems in humanitarian aid. Question forms are reviewed in the following section. Surveys previously deployed in the aid sector have suffered from poor usability and ineffective design (UN Action Team 7 on Disaster Management). These elements are important for a workforce which is subject to extreme time pressure and which may operate with restricted resources.

6.3.2.2. **Dissemination**

Just as in the forestry survey, forms were disseminated electronically via the internet. In the case of humanitarian aid, electronic mailing lists and an online journal were used to distribute the questionnaire. The survey forms were available as Microsoft Word documents for download, and a web page containing an online version of the form was maintained. Users were encouraged to use the web site if possible, although forms could be emailed and received by post. In addition to Internet mailing lists, around thirty individuals from within UK universities and industry were sent the form directly, with prior consent. The user-group of the Reuters AlertNet service was also consulted.

The primary dissemination methods provide three important validations: they ensure that sources are moderated, that the request for participation is not unsolicited, and that the user-group is knowledgeable and focused. The use of an online journal confers additional benefits because a record is held remotely within a searchable document archive. Even users who do not subscribe to the journal may read the information request while searching for associated terms. Electronic dissemination was employed because it is a low cost approach, which enables a very large number of aid professionals to be rapidly contacted. Options such as hard-copy postal distribution were considered and rejected on the grounds of cost, time lag and practicability.

In addition to general considerations, several key characteristics of the humanitarian aid sector advocate the use of electronic dissemination. Many aid workers operate in areas with little or no service infrastructure; postal surveys are ineffective for reaching zones of complex emergency and natural disaster. Humanitarian professionals are also highly itinerant, but most have access to email which is used to contact head office and for inter-agency cooperation. The internet provides the most stable platform for administering a survey although it was noted that the bandwidth available to humanitarian assistance workers may be very limited.

6.3.3. **Participant Groups**

Six groups of users received the survey. They comprise three mailing lists, an online journal and two private contact lists, as shown in Table 6.1. Around 9,000 individuals received a request to take part in the survey. Response rates and data handling are discussed in section 6.3.5.

The UN mailing list administered by the Office for Outer Space Affairs focuses on policy-makers and intergovernmental staff; although membership is moderated the list is not restricted to UN staff and offices. The Disaster Research mailing list is inter-disciplinary and contains many active aid professionals. A separate subscriber list of almost 500 members is for readers who request automatic e-journal delivery via email. The JISC Natural Hazards and Disasters list is composed mainly of UK-based university staff and researchers. The choice of such lists provides an important and balancing perspective when it is considered that the Reuters AlertNet member-list comprises 392 active NGOs working in 90 countries. Reuters AlertNet members were selected following guidance from Reuters staff regarding the organisations that could assist, and most regularly used spatial data. Reuters AlertNet member inclusion was edited because Reuters Foundation has an obligation to protect member organisations that do not wish to be included in such surveys. The AlertNet membership is not designed to provide a pool of survey candidates. The large variety of organisations reflected in the edited list is not thought to have introduced significant participant bias.

Table 6.1 Statistics of Survey Readership and Response

Source	Number of Recipients
UN Office of Outer Space Affairs Mailing List	5,100
Disaster Research Mailing List	3,000
Disaster Research e-Journal Subscribers	496
JISC Natural-Hazards-Disasters List	263
Selected Reuters AlertNet members	150
Total Readership Exposure	9,009
Website Survey Visits	762

The mailing lists used act as a discussion forum, providing linkages between hazards and vulnerability specialists, field workers, and strategic staff from disparate locations and agencies. It was possible to subscribe to the lists and monitor threads of discussion prior to submitting the information request, to avoid inappropriate survey dissemination and resulting bias. The survey was available at three levels: the field user, the research scientist, and the policy- and decision-maker.

In addition to mailing lists, an invitation was included in the foreword of the questionnaire which asked users to forward the questions to interested colleagues. In this way the dissemination was more widespread, but readers were contacted in an organic yet focused way.

6.3.4. Questionnaire Discussion

In this section the overall logic, format, aims and objectives of each question are discussed. The full questionnaire is included in Appendix 2.

6.3.4.1. User Data

Q1: What is your name?

Q2: What kind of organisation do you work for?

Q3: What are the name and email contact details for your organisation?

Q4: What is your role in your organisation?

The first four questions collate business contact information using the very simple fields of name, organisation type, email address and professional position. This kind of respondent information provides an insight into the possible origin of bias or skew of results. These questions fulfil a second role of putting the candidate at ease because they can be answered rapidly (McKeown 2003).

6.3.4.2. Filtering Questions

Q5: Do you regularly use geospatial information?

Q6: Do you make use of [a selection of data types, with relevant check-boxes]?

The next two questions were qualification tests (known as filtering questions), designed to evaluate the appropriateness of participants. Further to this, question six describes the experiential categorisation of respondents: those who use infrared aerial photography can be identified, for example. Additionally it is possible to group all users who have comparative experience, (every user who has used Differential GPS and satellite images for example). It was helpful to refer back to question six when evaluating free-text questions later in the survey.

6.3.4.3. Vitality

Q7: Which of the sources you have checked are the most vital to your work?

This question requests that users make a subjective judgement; which of the data types they use is the "most vital"? Note that "useful" is not used and has a different connotation. Vitality in this context refers to capabilities that are reliant on a data source, not the general utility of that data. This field was a sentence-length free-text box to allow users to express any complexity they found.

6.3.4.4. Problems and Solutions

Q8: What limitations or problems have you encountered with data collection and management?

Q9: What solutions have been developed to work around these problems?

Question eight requests personal experiences of "limitations or problems" with data collection and management. It is an open question with a free-text box. Several issues are explored through this question: expectations of data, uptake and service delivery problems, and processing expertise. Question nine investigates the solutions developed by aid workers to problems they encountered. Research by Jones et al. (2004) suggests that within the humanitarian aid sector there is great "variety and ingenuity of attempts to find ways round" problems of data availability. The scope and extent of independent problem-solving activities provides an insight into potential failings of data providers: they may not respond to the needs of their customers. In a sector as broad as humanitarian aid, perhaps there is no such thing as a 'typical' user, and data providers struggle to develop generalised products.

6.3.4.5. Working Practices

Q10: What measures could be taken to improve the access, efficiency and simplicity of data supply to the aid community?

The tenth question is the first to explore multiple themes leading to a discussion in the free-text area. Participants were invited to explain strategies developed to mitigate problems encountered using Earth Observation data. The question builds on question nine and asks for a judgement ("what measures could be taken to improve") in three areas: data access, supply efficiency and simplicity. The question demands user creativity: they must plan a 'new way' of delivering services based upon personal experiences. It is possible to validate retrospectively the choice of themes - access, efficiency and simplicity – using answers to question eight.

6.3.4.6. Data Delivery

Q11: What key information do you most commonly need for response, preparedness and monitoring activities?

Q12: What time lag is normally associated with the acquisition of geospatial information? What is the most rapidly available data format?

Questions 11 and 12 are experiential. They draw the respondent away from creativity and back to applied issues. These questions are information-gathering. Their purpose is to survey the range and distribution of data requirement, and the effectiveness and robustness of data delivery.

6.3.4.7. Timeliness

Q13: Would more rapid access improve your response effectiveness?

This question draws on issues of timeliness. Is respondent capability limited, and therefore defined, by rapidity of data access? If users comment that improved data access would allow them greater capability, linkages can be made to issues raised in question 10.

6.3.4.8. Information Currency

Q14: How often should geospatial data be updated?

Previous questions analyse the delivery of product to user, but question 14 addresses a different problem; the currency of information, asking how often data should be updated. It is expected that a very broad range of responses will be received in line with the diverse range of activities undertaken by surveyed user-groups. When evaluating response, themes of requirement are expected to emerge. It is therefore possible to characterise the data update requirements of disaster managers, for example, and to compare them to vulnerability specialists and food aid administrators. The extent to which data sources can match the needs of user groups comprises a large component of value; matching needs with dataset characteristics is essential.

6.3.4.9. Preparatory Data Collection

Q15: How useful is pre-event data [a selection of checkboxes]?

This question investigates the extent to which pre-event data is considered useful. Ongoing programmes of disaster preparedness and the creation of global data clearing-houses covering vulnerable regions demand the collation of data for large areas (Peduzzi et al. 2005, CRED / EM-DAT 2006, section 6.1.1.2). Geospatial and meta-data is collected even when no hazardous event has taken place. Emergent issues surround the exploitation of pre-event data for planning and capacity-building activities, yet the most common use of such data is in an immediately post-disaster base-mapping phase.

6.3.4.10. User-Awareness

Q16: How familiar are you with the following satellite data sources [checkboxes for Unosat, Reuters AlertNet and Respond]?

The user-group penetration of three satellite data programmes capable of supplying geospatial information to the humanitarian community is assessed; the programmes are UN Unosat, Respond and Reuters AlertNet. The programme objectives overlap, but all are administered by different entities and have been publicised with different emphasis. It is possible to compare their current position in the consciousness of aid workers.

6.3.4.11. Survey conclusion

Q17: Are there any issues relating to this survey that you would like to raise, or comments you would like to make?

Q18: Finally, are you willing to be contacted again in the course of this research?

Questions 17 and 18 enable further interactions with the user-group in two ways. Inviting comment allows participants to raise issues they feel were not well-represented. There is also scope here for respondents to elaborate on points they made in earlier answers, or to provide further references or links to other work. The final question aims to establish a conduit for further personal discussion. It is possible to measure engagement with the research by using the number of individuals who authorise further contact as a proxy measure.

6.3.5. Data Handling

6.3.5.1. Statistics

It is difficult to establish how many potential recipients received invitations to take part in the survey. Using membership statistics for mailing lists and journal subscription information, it is possible to build a picture of possible numbers. All invitations included a hyperlink to the survey website. The number of unique visitors to the page was logged between January and May 2005. Of 9,009 potential visitors, 762 visited the website representing an 8.5 per cent invitation participation rate. Using the internet statistics, in combination with the number of completed surveys received, it is also possible to approximate the overall response rate: 9.8 per cent, representing 75 complete surveys from 762 visitors. This estimate may be conservative because potential respondents who downloaded the Word document are excluded.

6.3.5.2. Information Management

Questionnaires were available in two forms; a web-based email template and a Microsoft Word document. To avoid introducing bias it was important to ensure that surveys were accessible to sectors of the aid community working with limited bandwidth, and those workers unable to spend long periods online. The Word form was small in size (120kb), and could easily be forwarded within agencies via internal email. 27 per cent of responses used the offline Word document, indicating that it was worthwhile to provide alternative means of submission.

The survey submission period was January 2005 to May 2005. Removal of test submissions and an incorrectly completed form gave the final result; 75

forms were included in the survey discussion and statistics. To reduce the possibility of fraudulent responses, the questionnaire fields requesting respondent name and email address were mandatory.

```
Respondent 16

My name is
I work in an UNmore, within the UNEP-WCMC department.
My agency is called UNEP World Conservation Monitoring Centre
E-mail
This is my job: Internet and GIS Manager
Use geospatial: (Yes check) / (No )
Use: Ground groundsurvey
Map Mapping
Gadgets  (pda ) (gps ) (dgps ) (other )
Airphotos: airphotos (vis checkbox) (IR checkbox) (XS checkbox)
Satellite? Multiple including Landsat, Ikonos, Aster and Quickbird
Redrawing? redrawing
Which are the most important? map Interpretation
Limitations: Data size
Solutions: Reduced resolution
To improve: Promotion of Disaster Charter/UNOSAT
Need Coastlines
Have to wait 1-2 hours for archive multiple days for new acquisitions
More rapid access (good checkbox) or (not )
Data update: Monthly
Pre-event: (v.useful checkbox) (useful ) (slightly ) (not very )
Uno (yes checkbox) (no )
AlertNET (yes checkbox) (no )
Respond (yes checkbox) (no )
Other comments:
Contact? (yes checkbox) (no )
```

Figure 6.4 A computer script output was used to standardise the formatting of survey responses and assist interpretation and coding.

Because of the very large number of recipients compared with the forestry survey, responses submitted by email were filtered and automatically encoded using a script written into the structure of the online form, as illustrated by Figure 6.4. This ensured that each form was received with identical formatting. Blank fields in the template were automatically populated with user-generated responses. The script ensured that all mandatory survey fields were completed. The forms were designed to be assimilated into a database, to enable rapid searching and sorting. 55 forms were received in this way.

In cases where the respondent preferred to complete an offline Microsoft Word document, the form was locked, and non-editable fields were used to record the time and date of form completion. Areas designated for user responses were editable, but the rest of the document was locked and password-protected. This ensured that users were not able to alter the document structure. To preserve the internal consistency of data, it was decided that Word submissions would be encoded into the internet form before processing. Of the 75 responses, 20 were received as Word documents.

At an early stage in the design of the survey it was decided that to comply with data protection guidelines (UK Information Commissioner's Office 1999), respondent anonymity would be preserved by randomising and labelling questionnaires, as shown on Figure 6.4. This was achieved by arbitrarily associating each form with a unique respondent number, which is used in place of the respondent name – there is no link between the two identifiers. When information from comments could reveal the affiliation of a respondent, specifics have been removed. Respondent names and professional capacities are only used where permission has been given. Prior to completing the survey, several respondents requested clarification of the extent and purpose of the data that would be stored.

6.3.6. Questionnaire Responses

6.3.6.1. User Data

To enable accurate monitoring of survey penetration in various user-groups respondents were asked to label themselves into the following groups:

- National Government
- Local Government
- United Nations (users were asked to specify their department)
- Donor Organisation (users were asked to specify)
- Non-Governmental Organisation
- Commercial Enterprise
- Other (users were, once again, asked to specify).

Where there is an option to further specify, a free-text box was provided. Particularly in the case of the 'Other' category comments in this box were extremely useful and include 'academia' (16 per cent), 'disaster management' (3 per cent) and 'meteorology' (4 per cent).

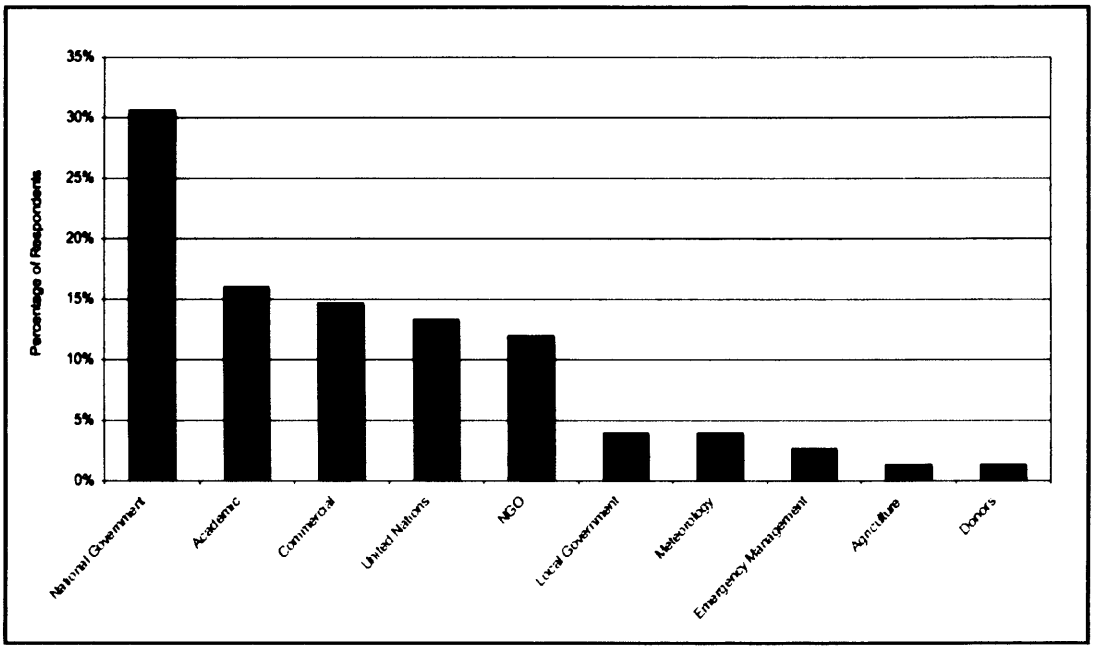

Figure 6.5 Professional capacity of survey respondents.

Five major groups dominate responses, shown Figure 6.5. The largest group comprises employees of national governments; almost a third of responses (31 per cent). The next group of respondents, comprising 16 per cent of the total are from the academic sector, well-represented in newsletter submissions and journal readership. It is perhaps unsurprising that the most technologically-connected elements of the humanitarian aid community were also most likely to return the questionnaire: they have access to extensive communications infrastructure and bandwidth. Academic users are more likely to have the technical awareness and capabilities to complete an online survey. This introduced a bias towards information-users.

Technical awareness and accessibility may have also contributed to the position of commercial entities, who are the next group accounting for 15 per cent of responses. Following poor market development and commercial penetration in the aid sector, and the resultant knowledge-gap, it is perhaps surprising that commercial interests are so well represented in survey readership. Completed questionnaires were received from image providers, satellite owner-operators, consultancy companies and value-adding firms. This may indicate renewed interest in serving the needs of a rapidly developing sector which increasingly relies upon space-borne sensors.

As the most influential single entity the dominance of the United Nations is expected: 13 per cent of responses state UN affiliation. Staff from a wide variety of departments and disciplines are represented, including UNOPS (UN Office for Project Services), UNITAR (UN Institute for Training and Research, WHO (Word Health Organisation), UNEP (UN Environment Programme), UN OCHA (Office for the Coordination of Humanitarian Affairs), FAO (Food and Agriculture Organisation), Unosat (administered by UNITAR and UNOPS), UNHCR (UN High Commission for Refugees) and UN GFMC (UN Global Fire Monitoring Centre). The range of activities undertaken within the UN mandate means that the requirements for geographic data are broad-ranging. Bjorgo (2002) states that "UNHCR was among the first to use this new technology for IM (information management) directly related to refugee assistance in the early 1990s", an approach that has become more widespread with improvements in bandwidth, data availability and image processing software.

The final significant user-group comprises non-governmental organisations (12 per cent). Lobbying and fund-raising activities mean that these entities have the highest public profile of all humanitarian agencies, yet their response to the questionnaire has been limited. Many NGOs choose not to take part in research questionnaires for a number of reasons, including historical over-exposure of their staff to requests (Twigg, 2005, personal communication). In many cases requests for collaboration could not be delivered specifically to those with the greatest experience because press-relations staff handle incoming email messages. In other organisations, overworked staff may not have time to issue questionnaire responses. Investigation of NGO workload is insightful.

> Desk and programme officers could play a major role ... but they have very heavy workloads and are generally too busy with their ongoing concerns to reflect on or absorb new ideas. One of the most significant, and emphatic, findings of our research is that overwork and pressures of work are not minor factors in NGO operations and performance but *systemic weaknesses*. In our view, this is a major obstacle to the uptake of new approaches (Twigg and Steiner 2003).

6.3.6.2. **Targeting**

When analysing the qualification question, 94 per cent of respondents "regularly use geospatial information" in the course of their work. The remaining six per cent were composed of one abstention and four negatives. It is noted that a negative response does not exclude participants from taking part in further questions; in this case responses included a senior information technology technician, the CEO of a major charity and the Operational Director of an NGO specialising in post-disaster interventions. All made valuable contributions in later stages of the survey.

Question six involves detailed investigation of the relationship between users and six types of data. Participants were free to select as many or as few sources as were applicable. The question was followed by a list of options with check-boxes containing common data types. Question six represents the most thorough user cross-examination so far; results represent the percentage of users who selected the data type (shown Figure 6.6). Some had extensive experience with many data sources and others abstained from this question entirely. During the encoding of survey responses it was decided to simplify results; fragmented minor classes were subsumed within 'Field Devices' and 'Aerial Photography'. Subsets were processed separately and include classes for Personal Digital Assistants (PDAs), Global Positioning Systems (GPS), Differential GPS and Other devices. Visible, Infra-red and Multispectral photographic sensors are summarised in the same way.

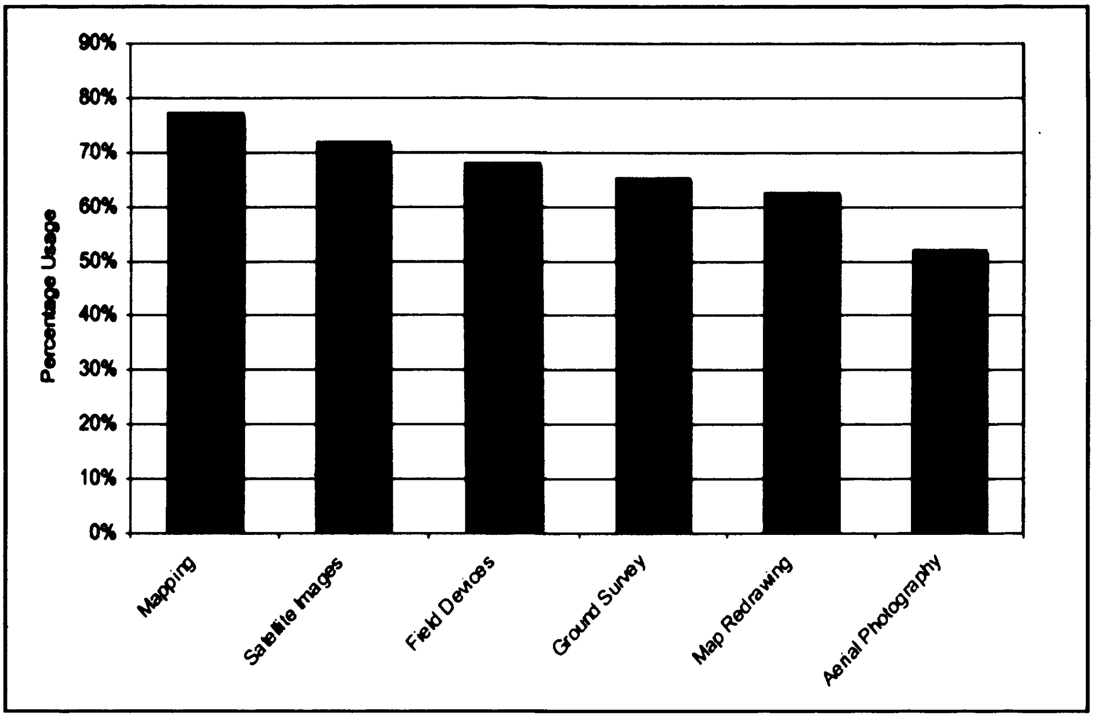

Figure 6.6 Data types used by survey respondents

The most commonly used data source is mapping: 77 per cent of users use maps. Further iterations of the questionnaire could aim to establish the source and format of mapping. Aid professionals in the field and in home-nation offices use geospatial data at all scales, from global strategic planning to sub-regional infrastructural capacity-building. In many cases the use of maps remains the most effective and robust way of imparting spatial knowledge, and many benefits of hard-copy maps cannot be replicated using any other approach. Even when a Geographic Information System is used, mapping remains a core requirement. Additional map features such as place names, route numbers and symbolic layers such as airfields can be extremely valuable in aid activities (Yassinov 2004, personal communication). Even with the most advanced satellite images, these components of added value are initially absent.

Global map products are widely available through the Internet. Many originate from strategic military mapping (VMAP0 and ONC-DCW (Operational Navigational Chart Digital Chart of the World), CIA World Factbook, Russian 1:50,000 city maps). Other products are available for download from online libraries and map servers. For larger scale regional maps, several services such as ReliefWeb, Reuters AlertNet and ESRI offer free maps for aid workers, which can be customised to suit a specific event. The internet has changed the way aid professionals use and acquire mapping, but it is not always possible to supply the required scale for aid activities, and many humanitarian aid professionals do not have reliable internet access from the theatre of operations.

In sudden-onset emergencies or natural hazard related aid interventions, the affected country often cooperates fully and can authorise the use of military mapping, which can also be provided by international peace-keeping forces (Douglas-Bate 2003). Use of government maps is inappropriate when humanitarian assistance is required on both sides of a disputed frontier. During the 2005 south Asian earthquake in Kashmir, the charity MapAction faced this issue (Irving 2006, personal communication). In such circumstances, the availability of geographic information of any kind can be restricted (*Nature*, October 2005). When intervention is the result of conflict or complex emergency, governing authorities may restrict the distribution of map products. In such circumstances, foreign nationals in possession of high-quality mapping may be at risk (Irving 2005, personal communication). Where data availability is limited or map sources inadequate, aid agencies cooperate to make best use of mapping, and a greater emphasis is placed on primary data collection activities and alternative sources of geospatial data.

When satellite data are used to create maps, they remain attributable to the satellite sensor for as long as the content is not substantially changed (by the creation of a topographic map, for example). Jones et al. (2004) state that "an Earth Observation image, albeit an orthorectified image, does not on its own make a map". Value-adding investments of time, equipment and intellectual capital are required for satellite imagery to become available to the aid community as so-called "image maps". These contain map features such as scale, north-arrow and geographic grid, but may include extra layers such as population density isolines, measures of snow thickness, or maximum daily temperature. One of the key activities of the Respond programme is the translation of data into information using image processing. In the aid landscape Martinez (2005) states that "an effective response mechanism to disasters [must be established] by providing not just raw satellite data, but transformed information and know-how for disaster management".

The next most commonly-stated data source is satellite images, used by 72 per cent of respondents. Satellite images are more widely used among this group than field devices, ground survey or aerial photography (which, as a once-core approach now only attains 52 per cent usage). Several factors explain the prevalence of satellite data sources among aid professionals, but one issue is dominant. A common frustration following humanitarian emergency is the lack of recent maps – one charity worker states that "lack of maps is possibly the biggest problem in emergency response" and another comments that "frequently we deploy with Michelin road maps ... in Afghanistan we only had Russian maps, and they were from the 1970s and in Russian" (Jones et al. 2004). The combination of factors that precipitate human vulnerability to natural events, such as lack of mitigation strategy and early warning, poor infrastructure and emergency response, occur most frequently in developing nations. The International Rescue Committee state that "in general, underdeveloped areas have not been mapped like those of developed areas, unless there has already been an emergency or war fought there" (IRC, 2004).

Maps cannot depict sudden or recent changes in coastline, geomorphology, frontiers, available transport links or land cover. These layers of data are key requirements during humanitarian interventions. When evaluating data sources, the International Federation of the Red Cross states that "you want something with enough detail so you can see whether building A is still standing or not, and it would be good to have something to tell you whether it was residential or not" (IFRC, in Jones et al. 2004). Vector-based building-level mapping is only available in few nations globally, and these advanced products cannot be rapidly updated after a natural hazard event. In the UK the Ordnance Survey only aims to incorporate changed features within six months (Ordnance Survey 2006). In addition, the effects of humanitarian emergencies do not end at national borders, as many maps do. Using satellite images as the basis for map-sheets allows continuous coverage of trans-national areas that may be poorly represented on fragmented map collections. Transnational coverage allows circumvention of national military restrictions imposed on regional mapping, leading to greater transparency and efficiency.

Using satellites, areas with no data can be mapped more rapidly, accurately and cheaply than would be possible using primary surveying methods, which have rarely been employed by humanitarian agencies. During many aid interventions there is no feasible scheme of primary data collection to provide emergency mapping in the absence of data, although technological innovations such as the "digital globe" of Google Earth may provide basic orientation data (Butler 2006). Alain Retiere of Unosat comment on data processing requirements.

> It has been a misconception among many providers of geographic information, in particular satellite imagery, that products necessarily need to be extremely accurate and complex. What we find is that for many end users, who have absolutely no data to start with, simple off the shelf products derived from satellite imagery are very useful. There is no need for complex and costly surveys if the requirements are for simple products (UN Special 621, 2003).

Statements from the free-text box of the sixth question (which queries the type of satellite data used) allow the popularity of different sensors and platforms to be assessed (shown Figure 6.7). Results are plotted according to how many times an instrument was mentioned by name. Some sensors, such as ASAR and MERIS reside on the same Envisat platform. Similarly, ASTER and MODIS are both flown on the Terra / Aqua satellite mission. 24 per cent of named sensor incidents refer to the Landsat platform, incorporating all versions of the sensor (Multi-Spectral Scanner, Thematic Mapper and Enhanced Thematic Mapper Plus). The lasting popularity of this instrument can be attributed to its useful band combinations (an approximation of true-colour is easily generated using RGB321 and RGB742 is very useful for geological mapping), long time-series of archived data, unrestrictive data policy and widespread long-term acceptance among the scientific and resource-management community (Lillesand and Kiefer 1994, Campbell 1996, Harris and Browning 2005).

The next most-frequently mentioned Earth Observation programme is the TERRA platform, including both MODIS and ASTER instruments. These sensors jointly account for 13.5 per cent of comments, and they have been widely used thanks in part to useful band combinations and good ground pixel resolution (also called spatial resolution) for ASTER, and broad coverage allied to validated vegetation- and fire-related consumer products for MODIS.

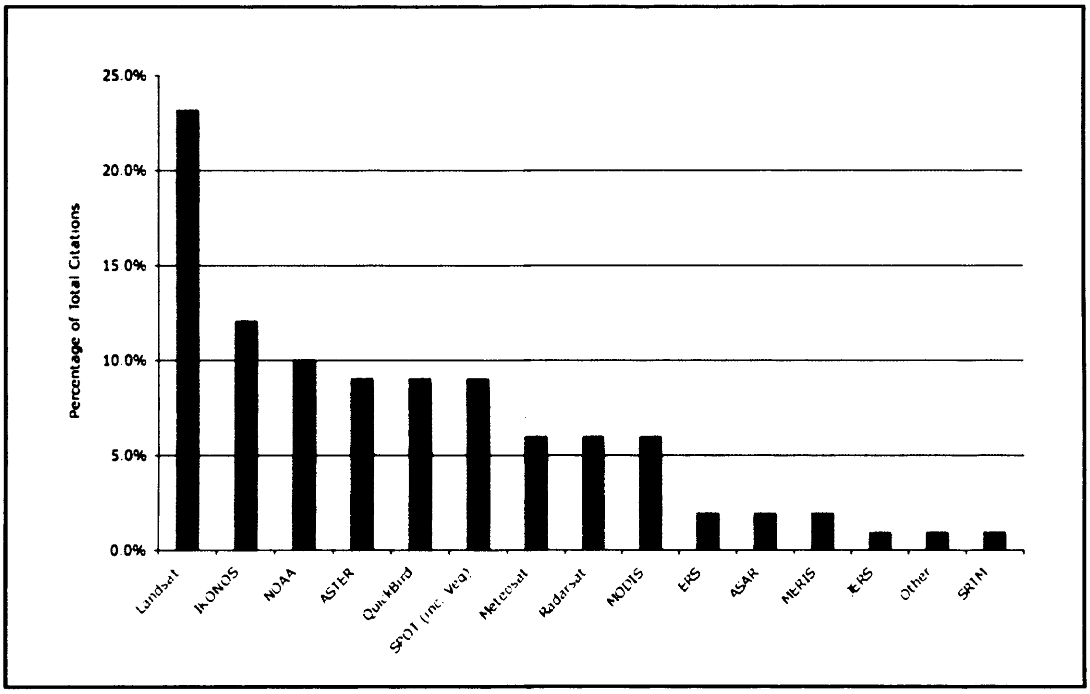

Figure 6.7 Satellite popularity, based on the frequency of citation by survey respondents.

The IKONOS sensor (12.5 per cent) is extremely popular among aid professionals due to its ground resolution of around 1 metre. Very high-resolution sensors with spatial resolution of below 4 metres have been used for humanitarian refugee-camp population estimation since the 2 metre resolution Russian KVR-1000 sensor became available in 1987, but the widespread commercial availability and active marketing of IKONOS has broadened activities in this area (Bjorgo 2000). IKONOS data has been extensively distributed through Respond for humanitarian use, which has generated large exposure of data to aid workers. This may partly explain the popularity of the instrument.

Huyck et al. (2005) state that "optical data is limited where the scene below is covered by smoke. Optical coverage is therefore of little value if fires are burning during the early phases of a disaster." In some circumstances this is the case, because "fires generate smoke aerosols and gases which... attenuate solar radiation directly through scattering and absorption" (Kaufman et al. 2003). However, it is not justified to generalise that non-microwave remote sensing has no utility in the presence of smoke. Kaufman et al. (2003) observe that "burn scars can be observed from the MODIS mid infra-red channels even in the presence of smoke, which is transparent at that wavelength range". Even in visible wavelengths Earth Observation has been successfully applied to the mensuration of large-area smoke plumes and Total Suspended Particulates (Kaufman et al. 1990, Cahoon et al. 1994, Christopher et al. 1995, all cited by Hashim et al. 2004). For smoke penetration, indices based on SWIR wavelengths have reduced the effects of atmospheric gases and aerosols, leading to the "ability to penetrate an atmosphere opaque with biomass burning aerosols... producing a realistic vegetation condition image" (Ben-Ze'ev et al. 2006). To date, these scientific approaches have not been employed in humanitarian interventions. It was therefore surprising that radar-based sensors were not more popular among disaster managers and aid workers; it was expected that the ability to easily penetrate clouds and smoke plumes (with no extra processing requirement) would be a vital asset. yet only 7 per cent of sensors named were radar instruments. Difficult processing and non-intuitive image interpretation may have limited uptake of radar sensors among non-technical users. Radar imagery is widely used in the generation of Respond and Unosat products (in addition to digital terrain models from radar sensors such as SRTM).

Faced with insufficient mapping aid workers may turn to primary field data collection, encompassing the next two categories in the survey response: Field Devices (68 per cent) and Ground Survey (65 per cent). The most popular field device was the Global Positioning System (GPS) receiver, which accounted for 57 per cent of usage. The decreasing cost of consumer GPS units, their increasing battery life and precision, and the rugged design of many new devices means that in many humanitarian applications their use has become almost universal. If GPS and Differential GPS are combined they account for 75 per cent of field devices. Almost 19 per cent of respondents used data from Personal Digital Assistants (PDAs) to support workers; devices which can be used to input data digitally in the field allow rapid processing and reduce data integration overheads.

Many GPS and PDA units are undoubtedly used in support of the next category; Ground Survey. Respondents suggest that aid entities do not undertake surveying to generate maps, but collect and collate socio-economic information layers that are difficult to characterise using remotely-sensed proxy measures. Respondent 9 states that "unavailability of [suitable] data" is a problem which can only be resolved using "village to village surveys and the distribution of questionnaires to administrative staff". USAID FEWS (Famine Early Warning System) confirm the issue in their survey response, stating that "we need livelihood information to combine with imagery to better understand what [humanitarian] response might be needed". Socio-economic data is particularly important for some humanitarian interventions, such as food security monitoring; Twigg (2006, personal communication) states that "natural hazards [such as locust infestation, extreme weather or crop failure] are mediated through the socio-economic system before famine is produced".

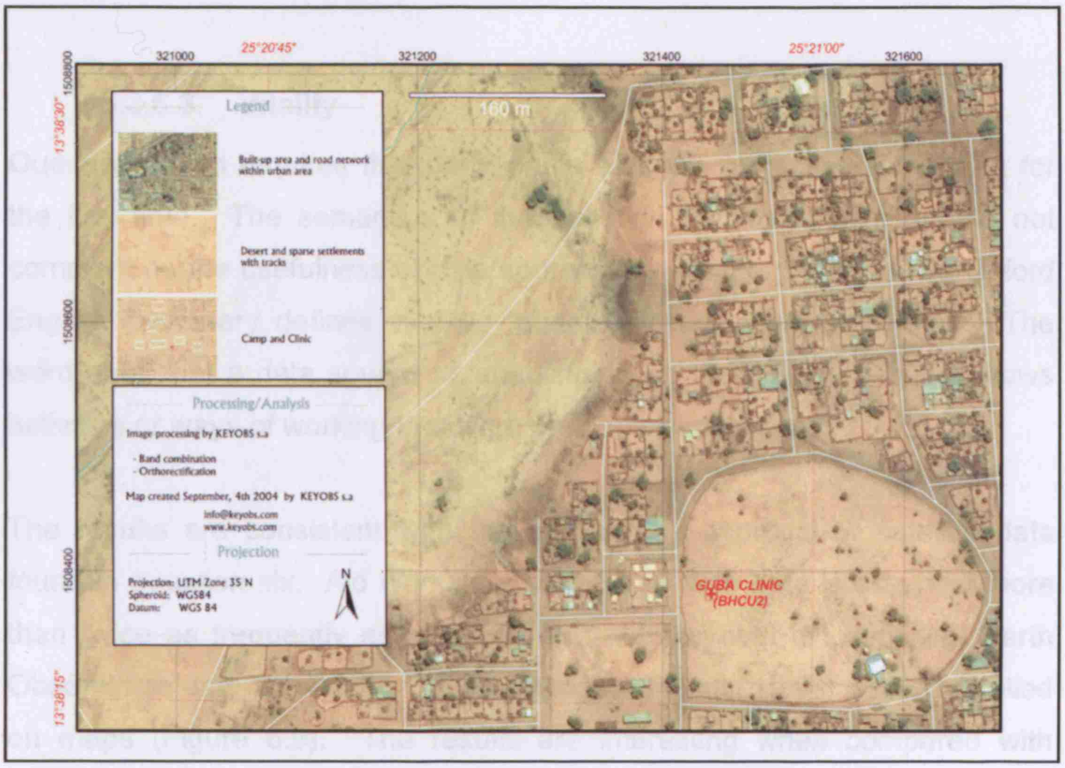

Figure 6.8 IKONOS image-map data allows aid workers to easily and quickly represent the geospatial characteristics of the spread of refugee camp infections using local GIS layers (Infoterra UK 2005)

In developing nations the absence of demographic, census or electoral data leads to uncertainties about the make-up of populations. If communities comprise large numbers of very young or old people, their resilience to hazards such as cold weather, malnutrition and disease may decrease. In areas with high disease transmission risk, such as larger refugee camps, it is possible to map possible vectors of disease by accurately recording the date and position of each infection using very high spatial resolution data (Figure 6.8), as at Guba in the Darfur region of Sudan (Veck, personal communication, 2006). This example illustrates the enabling influence of increased-precision geospatial data, which has filtered down to affect the day-to-day activities of aid organisations. As Messick (2004) states "the change from 1:1 million scale tourist maps to data visualised down to one metre has provided opportunities to look at what the aid community does and explore how to do it differently".

6.3.6.3. Vitality

Question seven requires that participants express subjective judgement for the first time. The semantics of the question demand that users do not comment on the usefulness of data sources, but on their vitality. The Oxford English Dictionary defines vital as "absolutely necessary; essential". The word asks that a data source is 'enabling' more than 'useful'; that it allows activities or ways of working that were previously impossible.

The results are consistent with the very strong approval of satellite data found in question six. Aid workers state that satellite data is essential more than twice as frequently as anything else; 44 per cent of users find Earth Observation data "vital" to their work, compared to just 19 per cent who relied on maps (Figure 6.9). The results are interesting when compared with question six; it seems that as an approach, using maps is still more common than using image-maps, yet aid workers do not see maps as the key to new capabilities. The fact that less than one in five surveyed aid workers found maps vital to their work marks a significant paradigm-shift in a field reliant upon the supply, manipulation and interpretation of geographic data.

Investigating such a startling assertion by respondents, two small sampling issues warrant further comment. The first concerns the respondent composition, which is dominated by government and academic users (together comprising 47 per cent of received surveys). This user-group has controlled the research and development of remote sensing since the earliest satellite images became available, and academic and government interests still dominate the Earth Observation marketplace. Allan (1992) states that "Earth Observation systems ... have had national security implications which tended to enhance the perception that Earth Observation was a natural monopoly with services provided by governments".

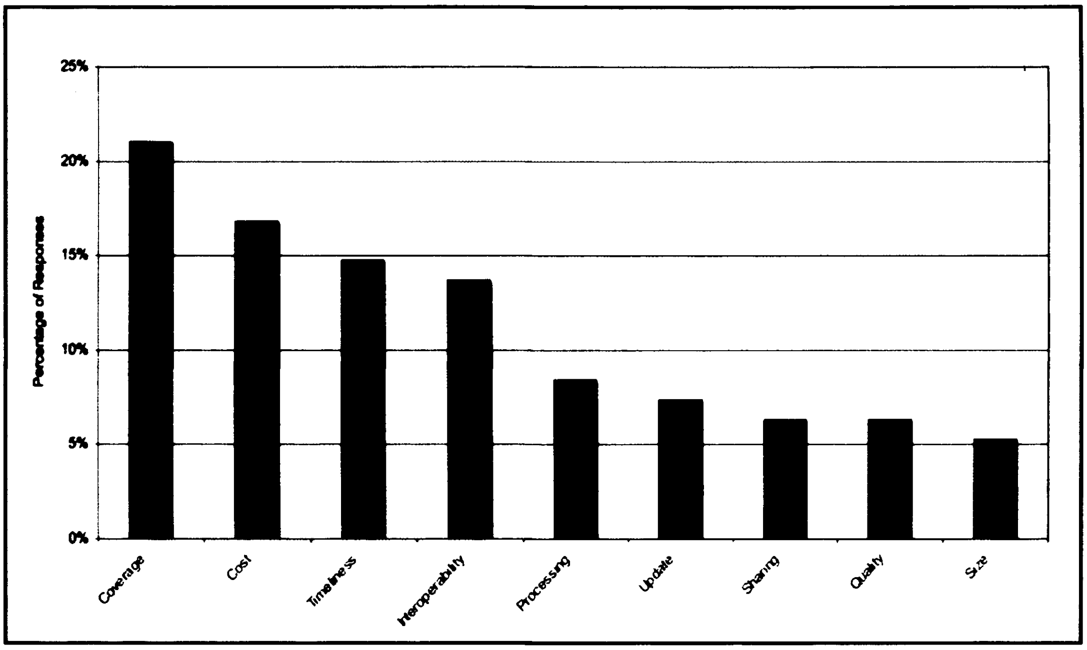

Figure 6.9 Sources of geographic information, according to the number of users citing it as "vital". 44 per cent of respondents consider satellite data most vital.

The second issue concerns the exposure of aid users to preferential data supply conditions. Mark Jones confirms that "from a financial perspective, humanitarian relief organisations are not an attractive proposition" for long term market development (Jones et al. 2004). The dominance of free- or very low-cost data may lead to artificially high uptake of Earth Observation approaches in the short to medium term.

Regarding vector-based cartography, publishers have been slow to make products available at reduced cost for humanitarian purposes, and have been unresponsive to a global market. The coverage of developing regions – especially Africa - is poor, and "electronic [map] copies are most valuable but the least available", state Merlin (in Jones et al. 2004), who go on: "often the only map available is a second-hand photocopy". Many aid professionals now investigate vector mapping products only when no digital satellite data is available.

Even when vector maps are required, several free or reasonably priced global map products are available via the internet, in addition to the specific map-server technologies deployed for the aid sector. IRC state that they "usually get on the internet and hope that UNHCR, ReliefWeb, Reuters AlertNet, or some other site has something we can download, modify and share" (International Rescue Committee 2004). GPS technology was vital to 11 per cent of respondents, aerial photography to 9.5 per cent, and ground survey proves vital for just 8 per cent of users.

6.3.6.4. **Problems**

Discussing limitations and problems, users expressed frustration with a wide range of issues, shown Figure 6.10. The free-text question form invited users to raise multiple issues and allowed users to priorities their responses. Every time an issue was raised, a vote was logged. As in question six, some users were effusive and others abstained entirely. Due to the phrasing of the question it is hard to be certain whether some users referred to satellite data, although most made this clear in their responses. Quotations only from respondents who have been clear about this issue are used. It was noted that further iterations of the questionnaire require a clearer expression of question requirements.

The most common stated problem was securing access to data covering the exact area of interest, consistent with the conclusions of Jones et al., who state that "humanitarian aid workers in the field often do not have and cannot find maps of the target area that they need" (2004). 21 per cent of responses concerned access or coverage. Several users complained about cloud cover and incomplete datasets (respondents 27, 46 and 70). Further to this, 17 per cent of respondents noted that cost was a limitation in their collection and management of data. Respondent 43 explains that "acquiring satellite imagery for Disaster Management purposes is simply too costly in second- and third-world currencies; effectively this places satellite imagery out of reach". It was unexpected that cost would be such a priority for users in the presence of subsidised avenues for acquiring processed data. This could be for two reasons: perhaps the activities of some respondents are not covered by Respond, Unosat, Reuters AlertNet or ICSMD. Or perhaps eligible users are unaware of knowledge-gap bridging programmes, which are discussed in Section 6.2.1.

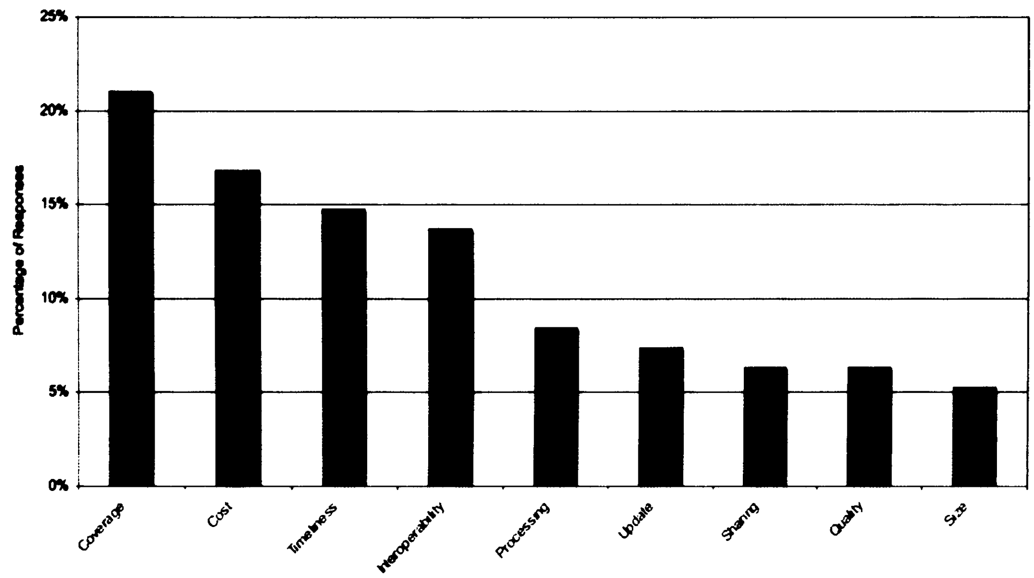

Figure 6.10 Limitations and problems of data access encountered by survey respondents. Availability and coverage were key issues.

15 per cent of responses stated that data could not be obtained in a timely manner. Most common among timeliness complaints concerned the lag between placing an order and receiving data- respondent 63 comments that "it takes too long!" Even in non-emergency situations, the time taken to acquire and process data remains an issue; Bjorgo states that this problem only applies to new-acquisition data, and that "the most rapidly available data format is what already exists in databases". On a related issue, 7 per cent of users highlighted data update or revisit frequency as a problem.

The other significant issue raised was one of interoperability and standards-compliance. Several users mentioned that specific "data formats [are] not always available" (respondent 74), or that "non-uniformity of data format and specifications" causes problems (respondent 72). The comment of respondent 33, who is affiliated with the NASA Global Land Cover Facility (a clearing-house and distribution centre for US satellite data) is particularly incisive; "Varying data formats are difficult to consolidate ... GeoTIFFs have the potential of becoming a universal data format that is manageable and potentially uniform".

6.3.6.5. Solutions

The ninth survey question investigates the solutions developed within the aid community to overcome problems. Some users provide practical solutions to the issues raised in question eight; for example, the following three users have different solutions. Firstly, respondent 5 notes that "cooperating with the UN and other donors" solves problems of the "high price of Remote Sensing data". Secondly, respondent 10 "depends on external organisations" for assistance with the costs of technology, and finally respondent 43 has to "do without the use of satellite imagery" for reasons of cost. Some other users were more proactive in their responses. Frustrated with problems of date update frequency and map-sharing, Respondent 19 established the Sudan Interagency Mapping Group comprising UN bodies, NGOs active in the region and national government departments.

In addition to field aid workers, comments were received from staff associated with data supply. Alain Retiere, director of Unosat, notes that although the cost of data and the mechanisms in place for sharing data are currently limiting, solutions can be brokered through "special discounts for humanitarians, partnerships with the research [community] to [enable use of] network infrastructure, a consortium of value-adding companies and the strengthening of Unosat as a one-stop shop for users". The influence of programmes such as Unosat is not universal, and respondent 54 is unable to use satellite imagery because it is generally unavailable before his agency is mobilised to the field. Médecins Sans Frontières (MSF) report the same issue and state that "no solutions were found: we've been working blindly due to the urgency of the situation." MSF recommend simplification of administrative procedures governing image acquisition; a recommendation in line with a Unosat objective to "streamline procedures and prepare data in advance" (Bjorgo 2006).

Question 10 requested that users design strategies to overcome problems of data "access, efficiency and simplicity". The clear outcome from this query was that the internet is the most useable and responsive medium for data dissemination, and that users feel there is a lack of centralised online distribution centres for satellite data; 17 users specifically mentioned online image storage and browsing. Respondent 44 states that the biggest requirement is to "centralise data distribution" and goes on: "I like the Unosat website, but you only get processed data there". There is wider approval of community-based web portals such as Unosat and Reuters AlertNet from respondent 4, who agrees that "internet access to protected websites that would allow two-way sharing of information" would be very useful. Again, it seems that strategies to address problems of data access have not widely penetrated the user-group; the United Nations Environment Programme (UNEP) confirm that one of the most pressing tasks is the "promotion of the Disaster Charter [ICSMD] and Unosat". Users seem largely unaware of the existence of "up-to-date satellite images via the internet" via a "simple web-based utility for accessing satellite images" (respondents 19 and 60). Existing mechanisms (Respond, Unosat, ICSMD and Reuters AlertNet) are discussed in section 6.2.

6.3.6.6. **Data Delivery**

The use of multiple terms in the question form and the provision of a free-text box invited users to provide discursive, creative answers. A wide variety of responses were received. They were grouped into procedural, hard and soft categories. Procedural requirements called for a change in the way aid is administered. Hard requirements are often data-dependent. The final category of responses request social information and centre upon complex information-gathering within human vulnerability contexts.

An example of a procedural response type comes from respondent 30, who states that he needs "immediate access to imagery" more than anything else. Hard responses are characterised by respondent 49, who needs "the location of bush fires, flood extent and land cover". Similar sentiments are expressed by respondent 13; "we need land use, digital terrain model and hazard maps". Hard responses are often transactional in nature and are also often achievable using remotely-sensed proxies. Determining land cover, for example, is a routine activity of image processors.

Many responses to question 11 are softer, and reflect social and cultural elements of disaster management. Human values and beliefs, such as those regarding community and religion, for example, help define the resilience of populations and contribute to measures of vulnerability. Requests for socio-economic meta-data underline the inputs to disaster management and aid that can come only from in-situ primary data collection. Collating information to measure the extent of collaboration between local communities and governance (respondent 76), the historical migrations of populations (respondent 63) or the number of trapped individuals (respondent 54) can only be established on the ground through communication and interaction with affected communities.

6.3.6.7. Delays and Data

This question requests that participants assess the time lag between ordering data and its arrival. How long does it take suppliers to serve the requested product, after the order has been submitted? Responses to this question are shown on Figure 6.11.

Results are grouped into two clusters, one in the hours-days range (45 per cent of users) and the other in the fortnight-month range (32 per cent). This represents grouped supply capabilities of sensors and image catalogues. Within the hours-days group, it is proposed that there are three groups of users – those using near-real-time sensors, those accessing archived data and those using emergency-response processed image data (such as the daily snow cover maps of Kashmir available through Respond).

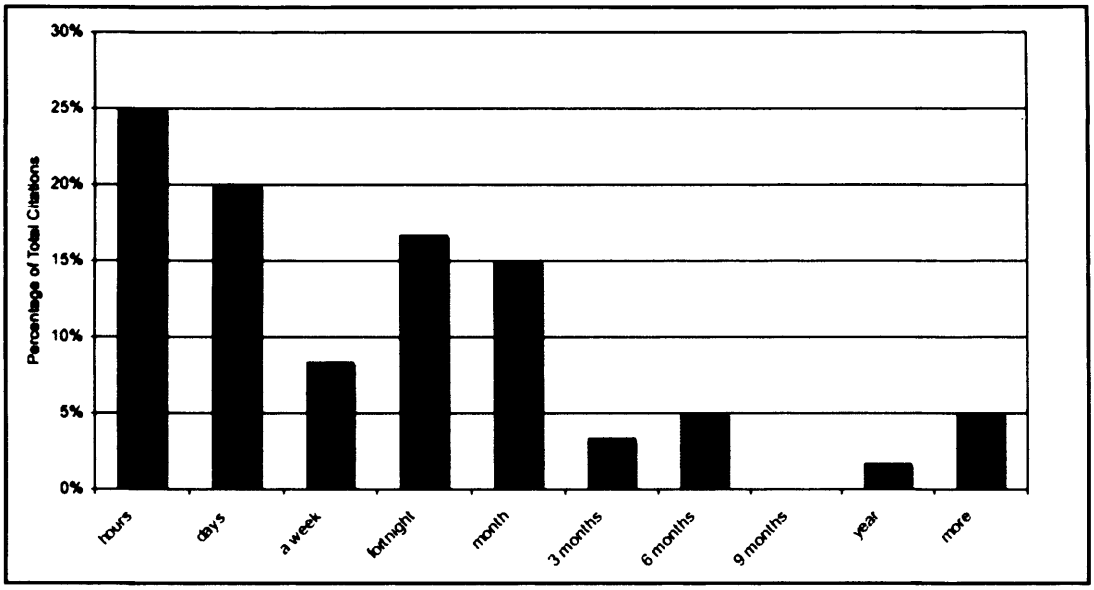

Figure 6.11 Time delay between ordering data and its arrival

Geostationary meteorological satellites typically downlink a new image every 15-30 minutes and data are made available to users in near-real-time. For continental monitoring, many aid workers use meteorological sensors and other high-orbit instruments such as the polar-orbiting AVHRR (17 per cent of users mentioned NOAA or meteorological satellites by name). Some users report data delivery as rapidly as "every several minutes" (respondent 21). Recent changes to the make-up of this user-group may be linked to the launch and successful test phase of the Disaster Monitoring Constellation, designed to provide daily revisits and near-real-time image processing, using a sensor with similar capabilities to the Landsat Thematic Mapper instrument flying on multiple low-cost satellite platforms (DMCii 2005, Table 5.1). Each sensor platform weighs around 120kg and acquires data using a push-broom sensor with 660km swath width. The growing Disaster Monitoring Constellation consists of six identical platforms equally spaced around a sun-synchronous orbit, enabling daily revisit of any location. Second-generation DMC satellites (such as Beijing-1, UK DMC-2 and Deimos-1) are capable of imaging 4000km along-track at GSD of approximately 22m. In support of humanitarian work, all DMC satellite operators donate 5 per cent of sensor time to disaster relief, with imagery disseminated through Reuters AlertNet, Respond and more recently ICSMD. DMC data has been used "to fill the existing 3-5 day [ICSMD] response gap" (DMCii 2007). Another group served in less than one day comprises those users who request archived data, most commonly from the Landsat sensor series. Even large volumes of data can be delivered via FTP (File Transfer Protocol) very rapidly through online image databases such as the Global Land Cover Facility (GLCF) and the eight NASA Distributed Active Archive Centres (DAACs).

Processed data is often made available within very short time-scales through both Unosat and Respond programmes. Voigt (DLR 2004) says of Respond: "you have to convert the data into images, then the interpreter has to convert all this into crisis, damage and situation maps. This kind of detailed analysis normally takes a couple of months but Respond gets it done in about 12 hours." Infoterra state that in the twenty days following the Asian Tsunami of 2004, 214 satellite image maps were created and disseminated by Respond (Veck 2005, personal communication), illustrating the large number of images available through these initiatives. Further to the work of Respond, the International Charter for Space and Major Disasters (ICSMD) was activated 20 times in 2004 and 25 times in 2005; each activation leads to rapid processing of large quantities of satellite data, which are available immediately via the internet (ICSMD 2006). Some recent activations are shown on Table 6.2.

It is proposed that many users waiting for between two weeks and a month may request new data acquisitions or submit tasking requests to so-called pointable sensors. This category of users includes those using new IKONOS, Quickbird and SPOT data. This group of sensors comprise 31 per cent of all mentioned instruments. Requests for data processing through Respond partner value-adding companies can also take around a month to fulfil if they fall outside the ICSMD or Respond remit.

Table 6.2 Recent activations of the International Charter of Space and Major Disasters, showing variety of locations and triggering events (available at www.disasterscharter.org)

Event	Location	Date
Earthquake	Chile	22 Nov 07
Floods and Cyclone	Bangladesh	16 Nov 07
Floods	Vietnam	15 Nov 07
Floods	Mexico	02 Nov 07
Flood and Hurricane	Dominican Republic	30 Oct 07
Fires	USA	24 Oct 07
Typhoon	Vietnam	04 Oct 07
Floods and Typhoon	North Korea	21 Sep 07
Floods and Landslide	Slovenia	19 Sep 07
Floods	Africa	14 Sep 07
Hurricane	Nicaragua	04 Sep 07
Fires	Greece	29 Aug 07
Fires	Paraguay	27 Aug 07
Hurricane	Mexico	21 Aug 07
Floods	North Korea	17 Aug 07
Earthquake	Peru	16 Aug 07
Floods	Vietnam	08 Aug 07
Floods	India (Bihar)	06 Aug 07
Forest Fires	Canary Islands	02 Aug 07

6.3.6.8. **Timeliness**

Question 13 is a 'binary-type' query designed to discover whether the data delivery time-scales illustrated in Figure 6.11 inhibit the activities of aid professionals. 85 per cent of respondents stated that more rapid access to data would improve their response effectiveness (Figure 6.12).

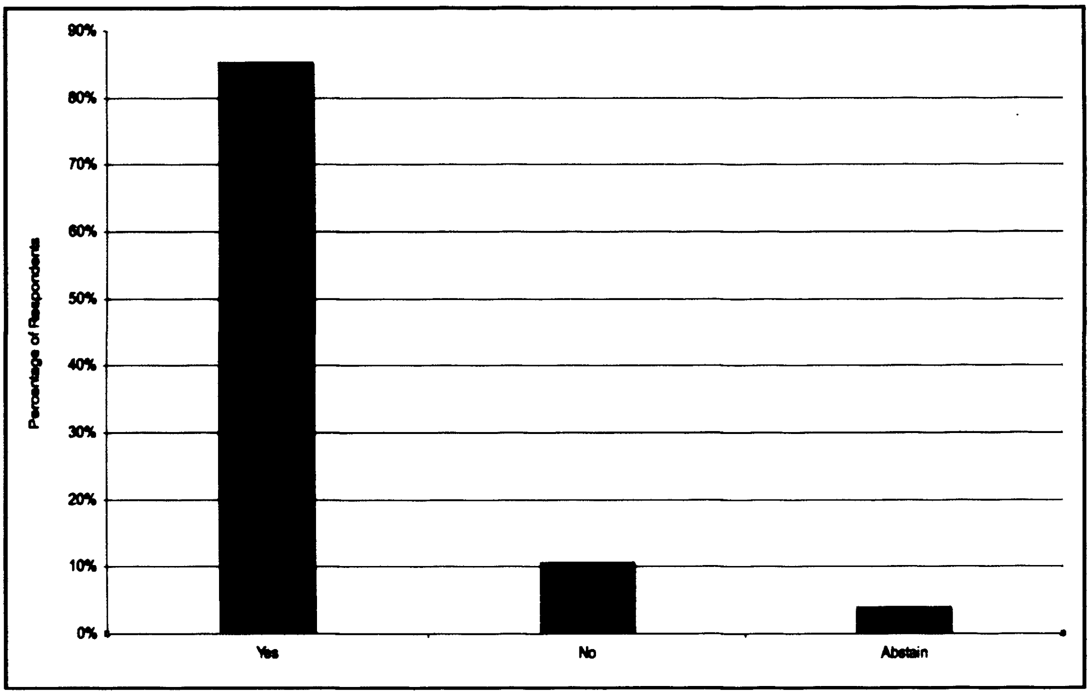

Figure 6.12 Respondents were asked if more rapid access to data would improve humanitarian emergency response.

11 per cent did not think data access was an impediment to activities and 4 per cent abstained. The outcome of this question is that user activities are limited by the rapidity of data access. It should be noted that in this study, the level of market-penetration achieved by Respond, Unosat and Reuters AlertNet was relatively low (between 31 and 37 per cent of users reported that they were "familiar" with one or more of the programmes). If over 60 per cent of users have never heard of such initiatives it is unlikely that they are aware of new conduits for the delivery of low cost, high-quality geospatial data.

6.3.6.9. **Currency**

When asked how often data should be updated, recipients form three clusters, representing differing interests and monitoring activities (Figure 6.13).

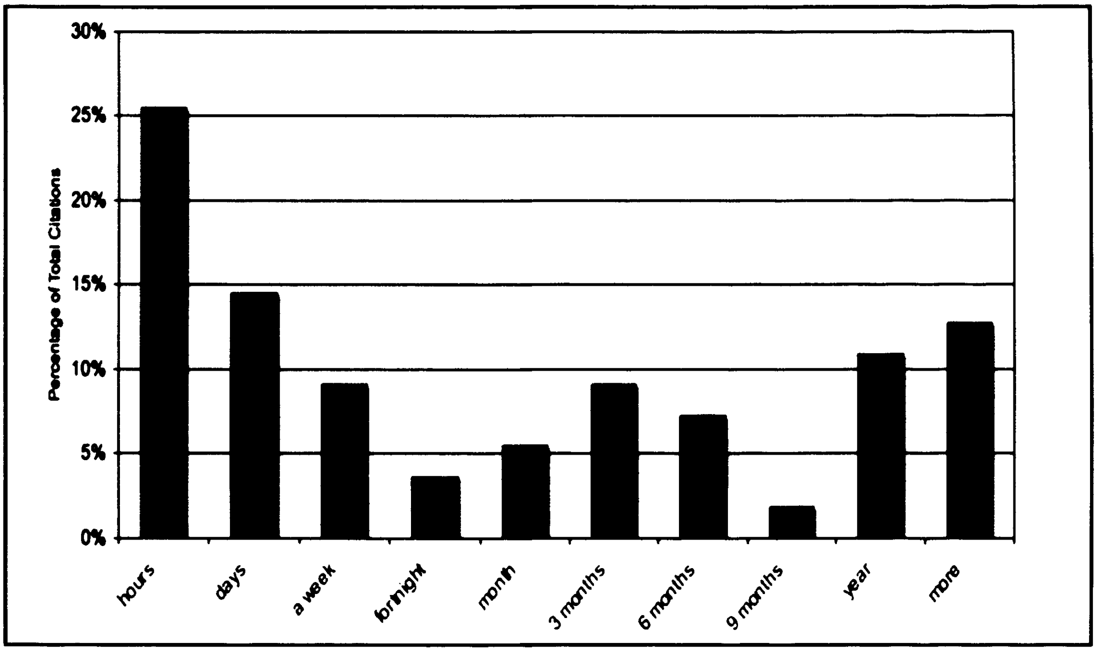

Figure 6.13 Update frequency requested by survey participants reveals three clusters of responses, which seem related to different humanitarian activities.

40 per cent of respondents stated that data would ideally be refreshed within hours or days, reflecting a need for situation-management and decision-support in the event of sudden-onset humanitarian emergencies. The needs of this group are served by Respond, Unosat and Reuters AlertNet, although marketing is required to increase the profile of all programmes (market penetration is illustrated Figure 6.14).

Figure 6.13 indicates a further 22 per cent of those surveyed preferred an update interval of between one and six months. It is proposed that these users are engaged in monitoring of ongoing interventions and developing situations. The ideal update-interval of 24 per cent of correspondents was one year or more, representing a requirement for recent base-map data. It should be noted that in sparsely-populated areas, relatively old images can be used for effective feature-discrimination and navigation. However, in developing nations where rapid urbanisation and land use change may be widespread, more recent images are preferable.

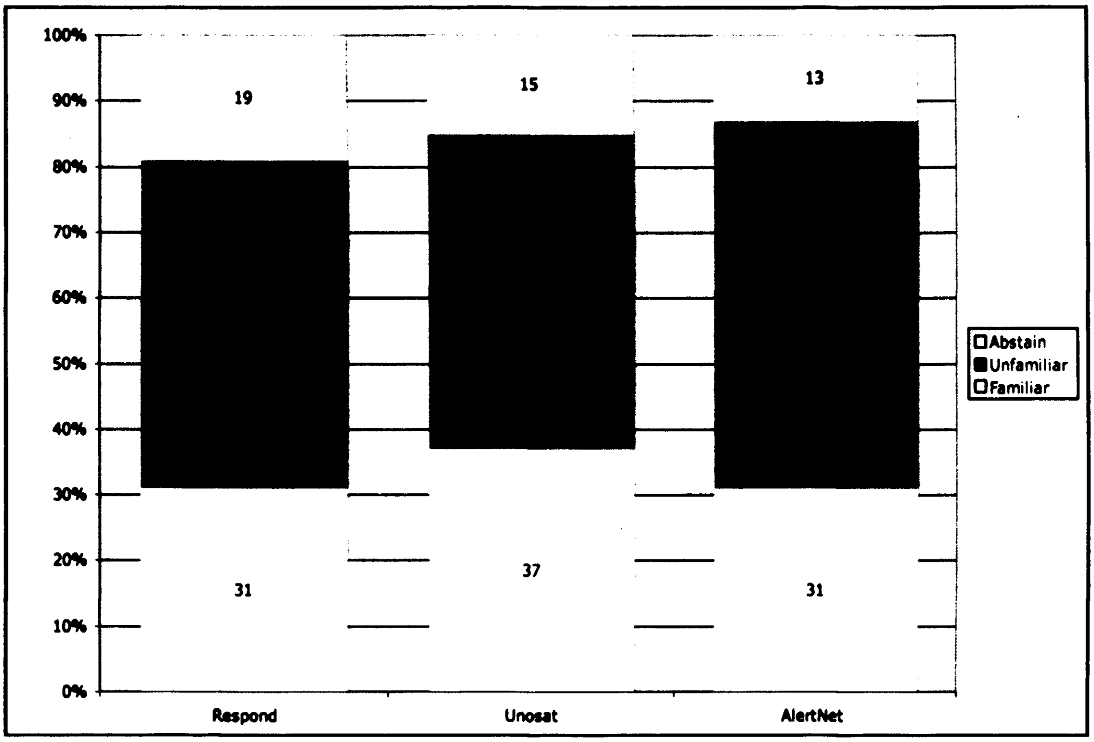

Figure 6.14 Users were asked if they were familiar with some schemes which facilitate the supply of free Earth Observation data to humanitarian actors. Although around a third of respondents were familiar with the programmes, around half had never heard of them. In association with Reuters AlertNet data which suggests that satellite images are in great demand by humanitarian workers, these results suggest that work is required to broaden the exposure of data provision initiatives.

6.3.6.10. **Pre-Event Data**

Participants were asked to categorise pre-event data as "very useful, useful, slightly useful or not very useful". Results are illustrated by Figure 6.15. 96 per cent of responses indicate that data acquired before a natural hazard event or emergency scenario was considered very useful or useful, indicating a strong user-interest in pre-emptively processed data.

Jones et al. (2004) identify the need for a global and "continuous imagery dataset, viewable at a scale comparable or better than the accompanying map data ... [which] would act as a background reference layer and as a basis for comparison". UN OCHA state that lack of data preparedness is one of the biggest limiting factors in their work, and that strategies in place for rectifying the problem include "pre-emptively processing topo-sheets for areas of concern". Another correspondent stated that "there should be a priority for acquiring 'before' archive material for disaster-prone localities around the world" (respondent 44).

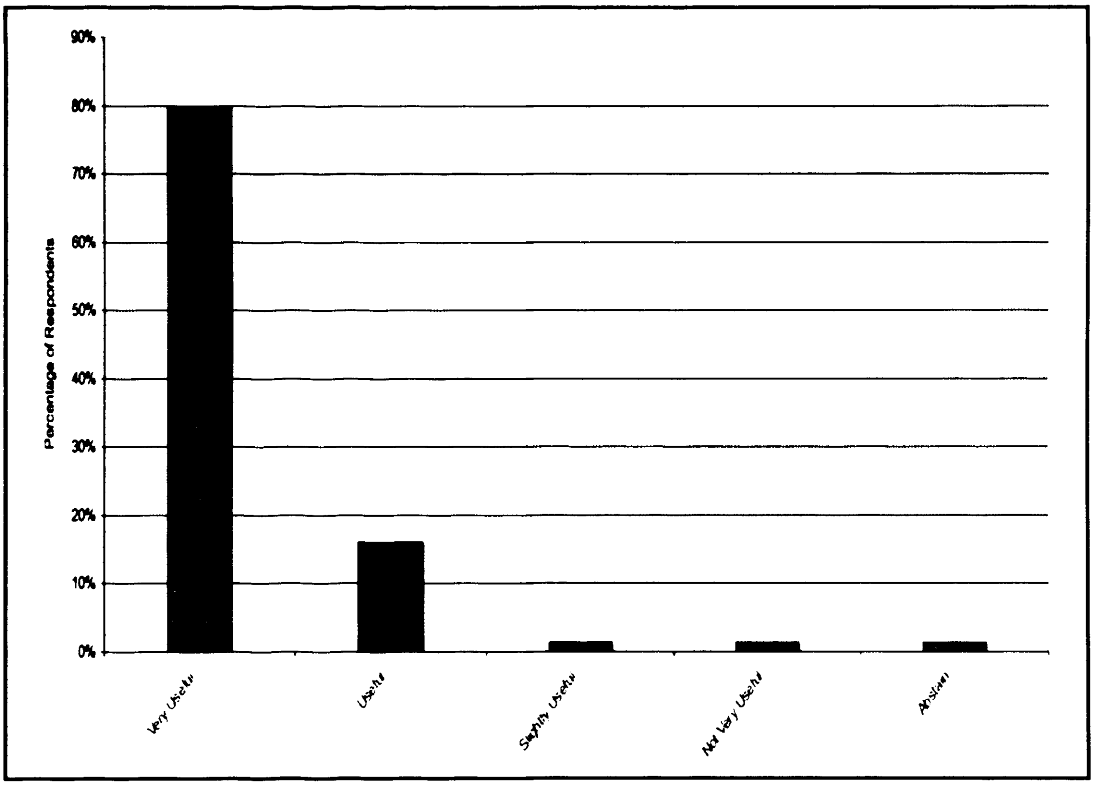

Figure 6.15 Respondents rated the usefulness of pre-event geographical data. 96 per cent of respondents categorise pre-event data as very useful or useful, revealing user interest in a preparatory data store.

In addition to providing the most rapid access (Bjorgo, 2005), archives of processed data could be used in other scenarios outside emergency humanitarian action. Longer-term international development, atmosphere-biosphere modelling, and regional capacity-building would benefit from a freely-available remotely-sensed optical dataset, at medium resolution and with near-global coverage. Global imagery datasets are available from Meteosat MSG, AVHRR, SPOT VGT, MODIS Envisat and NASA EarthSat, but none have been fully integrated with humanitarian work-flows and development work remains.

6.3.6.11. Issues and Comment

The final free-text area of the survey allowed respondents to raise issues or make further comments. 51 per cent of recipients chose to leave a message or comment. Users provided links to articles, (respondents 21 and 34), gave more detailed contact information (respondent 71) or elaborated on an issue using specialised knowledge (respondents 13 and 42). When asked if they could be contacted again in the course of the research, 92 per cent of respondents gave consent. There is clear potential for more detailed research in this area, beyond the scope of this chapter. In-depth interviews and focus group discussions are required for further study.

6.4. Conclusions; Humanitarian Aid and Earth Observation

Questionnaire responses and follow-up interviews together with an assessment of the needs of humanitarian aid agencies identified in the first parts of this chapter support the following key findings.

6.4.1. General conclusions

- Government agencies and the UN dominate policy developments
- Decision-makers and user groups which reside outside major agencies are disparate and fragmented
- Vector mapping and satellite images form the majority of data sources used in humanitarian aid activities
- Satellite data is more than twice as vital to aid activities as mapping, and the data appears to enable activities which are not possible using mapping alone
- 20 per cent of aid workers state that they cannot obtain adequate geographic data coverage of their area of operations

- 85 per cent of aid professionals state that more rapid access to geographic information would improve their capability to respond to humanitarian emergencies
- 40 per cent of aid workers would like to see geographic information regularly updated within a period of hours or days in the event of humanitarian intervention
- 96 per cent of respondents support routine and ongoing acquisition of pre-event geographic data in areas with identified vulnerability

6.4.2. **Satellite Data and Aid**

- Landsat and the TERRA platform are used most widely among satellite sources, which indicates the suitability of moderate spatial-resolution images for many aid activities
- Cost of data was a major limitation for 17 per cent of humanitarian aid workers, which may skew their choice of sensor towards low-cost sources such as Landsat; in some cases cost limitations forced the use of sub-optimal sensors
- Despite the high cost, significant user-groups make use of IKONOS and Quickbird VHR sensors
- Satellite data fulfils some information requirements of humanitarian aid work in a timely and cost-effective manner
- Earth Observation, which has no substitute for some activities, functions as an enabling technology in the humanitarian sector
- Satellite data can improve the efficiency of materials and personnel deployment in aid interventions, helping to prevent wastage and focusing the activities of aid entities more sharply
- Satellite data can support transnational humanitarian emergency work without requiring approval of the recipient nation, which is not the case with mapping. For this reason, satellite technology has enforced a shift in global diplomacy towards greater transparency (e.g. USAID confronting Sudan in UN Council meetings with IKONOS images of Darfur genocide)

- Satellite data can be a valuable input into natural hazard early-warning and human vulnerability monitoring in the academic and government sectors, and is the focus of continuing study
- Cost-based exclusion has become less widespread due to initiatives such as ICSMD, Unosat and Respond, which can subsidise or supply imagery. The most significant impediment to the success of such programmes is the poor market penetration they have achieved (around 51 per cent of survey respondents were unaware of the programmes)

6.4.2.1. **Limitations**

- Satellite data cannot replace paper mapping and on-site interpretation and analysis
- Unsupported application of Earth Observation data can omit vital layers of information, and can introduce interpretation errors which may not occur if site visits are used
- Users of Earth Observation data in the aid sector must still undertake primary field data collection
- Satellite data uptake is inhibited by institutional inertia and the internal traditions of aid entities. The data is perceived as being prohibitively expensive and 'high-tech'. This research suggests this is an out-dated viewpoint with limited ongoing validity

6.4.2.2. **Comment**

Survey responses, interviews and other communication suggest that Earth Observation data is not used to its full potential within the humanitarian aid sector. Uptake inhibitors exist on consumer and supplier sides, but the 'knowledge gap' is closing from both sides. The humanitarian aid community increasingly connect with global resources through the internet to share information. Because of the suitability of digital data for online distribution, and because of technological advancements, the negative influence of out-dated viewpoints and institutional inertia is in rapid decline, and many humanitarian workers recognise the positive impact new technology can have. For example, some find that satellite image-maps lack the complex symbology that limits the understanding of individuals unfamiliar with mapping conventions, so Earth Observation-derived information can be easier to use than traditional methods (DRK 2004). Institutional inertia remains a significant inhibitor, but in some cases, large agencies (such as the United Nations) provide proof-of-concept that satellite data can be successfully deployed in the field. IKONOS data was used in Sri Lanka and Indonesia following the 2004 Asian tsunami, distributed by the UN. Several questionnaire participants comment that the use of Earth Observation technology enables creation of geospatial information products that are independent of politics and national borders. This is especially useful because hazard events are commonly transnational in nature; sensitive frontier diplomacy was tested by the distribution of high-quality humanitarian maps following the 2005 Kashmir earthquake.

Within the data supply community several initiatives exist to provide processed satellite images free of charge for humanitarian use. Such programmes are recent developments, and their existence is not well-known among humanitarian workers. Frameworks such as Global Monitoring of Environment and Security (GMES) and the Global Earth Observation System of Systems (GEOSS) provide supporting policy and funding for the increased use of Earth Observation data for non-market societal benefit. Through the influence of such programmes, awareness of image-provision initiatives will grow, and there will be more opportunity for humanitarian workers to exploit satellite data in future.

When data are used to the fullest potential, they bring increased capability in offering assistance; agencies can help more people, in more ways, in more locations. The Public Good value of humanitarian work is reflected in the wide-ranging remit and funding of aid organisations worldwide, with the central objective of reducing human suffering. If a new approach improves capability in areas of humanitarian action, the intervention itself can be of greater scope and value. If any increase in capacity or capability is directly or indirectly attributable to Earth Observation technology and expertise, then data 'inherits' Public Good value, outside the influence of markets. The model presented below enables a measurement of the contribution of Earth Observation data to aid activities. This determines the share of aid capability that can be attributed to Earth Observation data. The model allows informed estimations of 'inherited' value. The humanitarian aid sector contributes to the value of Earth Observation by using satellite-derived information to deliver societal and socio-cultural global Public Goods which would not be possible without the data.

6.5. Development of a Model of Value

6.5.1. **Aims and Objectives**

A general model of value was designed and parameterised using data from the Forestry sector, described in Chapter 5. The general model is shown Figure 6.16. The model enables more complete evaluation of the potential and performance of Earth Observation data for non-technical users within four activity areas. Forestry professionals, with whom the model was developed, are commonly limited by budgetary constraints. Capability and return-on-investment from new approaches must be equivalent to those they replace. Using a problem-solution approach, elements of value which reside outside markets can be captured, and the operational contribution of Earth Observation data can be assessed.

Non-market value-types are omitted from many reporting strategies, but they account for a large proportion of the total value of sectors where market development is immature. Non-market value is also important when commercial exploitation of data is inappropriate or unsustainable, or where objectives are Public Goods. A large commercial market for data does not exist within the humanitarian aid sector, yet widespread adoption of geospatial information can yield large benefits that are Public Good in nature. An assessment of the information requirements of humanitarian workers, followed by a detailed consultation suggests that Earth Observation data sets will become more widely used in the next decade. Tools for decision-support can incorporate adaptable and extensible value-assessments which are not captured using traditional accounting.

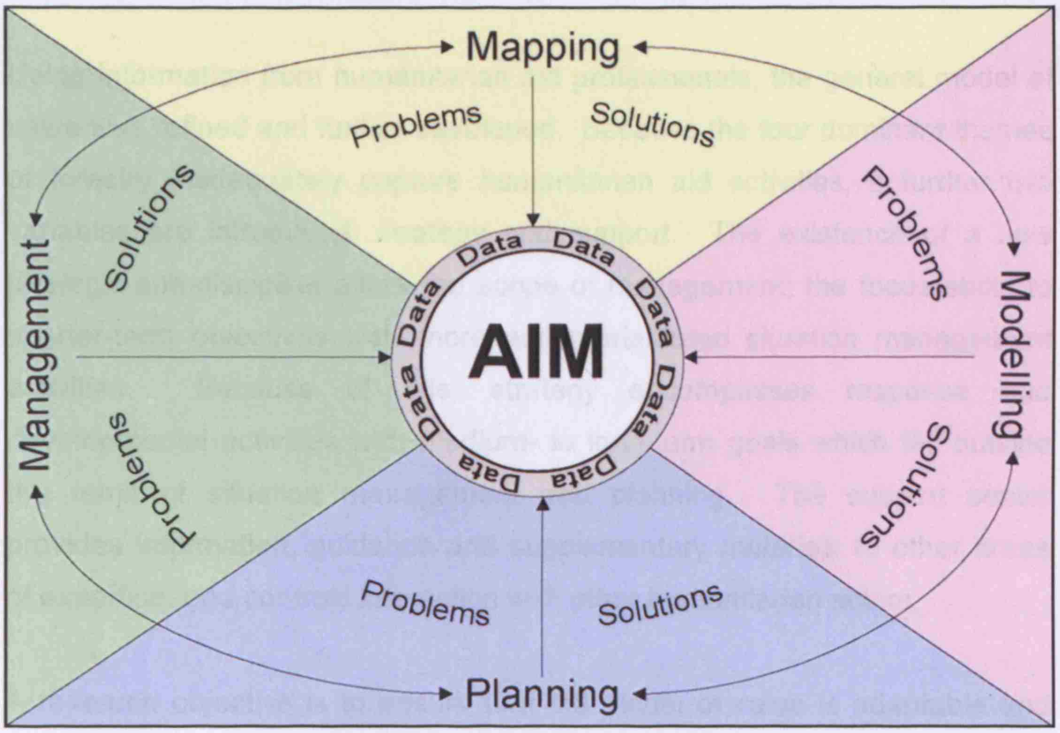

Figure 6.16 General model of value defined using the forestry sector. A full discussion of model development is included in Section 5.6.

6.5.2. Refined Value Model

Four broad schemes of activity exist within forestry. They are plantation management, mathematical modelling, mapping and strategic planning. A scheme for implementing the model is discussed in section 5.7.1. Once an audit of available data has been completed, each of the four model regions can be distributed to specialists and managers. Within each activity, focus groups and consistent analytical mechanisms (such as analysis of competing hypotheses or decision matrices) are used to independently assess the utility of data and make recommendations. Regional decision-making staff compile the model overview and assess the validity and cost-effectiveness of each model segment, weighting contributions by local factors which may include site development objectives, annual budget or staffing allocation. A greater number of positive sector scores indicates greater security of investment in Earth Observation and more potential for inter-departmental data exploitation.

Using information from humanitarian aid professionals, the general model of value was refined and further developed. Because the four dominant themes of forestry inadequately capture humanitarian aid activities, a further two variables are introduced; strategy and support. The existence of a new strategic sub-discipline alters the scope of management; the focus shifts to shorter-term objectives with more action-orientated situation management activities. Because of this, strategy encompasses response and developmental activities with medium- to long-term goals which fall outside the remit of situation management and planning. The support sector provides information, guidance and supplementary materials to other areas of expertise, and controls interaction with other humanitarian actors.

A research objective is to ensure that the model of value is adaptable and interoperable to allow deployment in diverse activities, as discussed in Section 2.3.3. The operational challenges facing foresters and aid workers are very different yet the model can meet their needs equally as an interdisciplinary management and decision-support tool. The model, defined using case studies within forestry and humanitarian aid, must be general enough to remain applicable in a wide range of contextual settings while providing useful insights into value.

An interim development, figure 6.17 includes the concepts of 'hard' and 'soft' activities introduced in the McKinsey 7-S diagnostic model, discussed below. Although a useful categorisation, the identification of 'hard' and 'soft' activities does not represent working linkages between themes of activity. To address this shortcoming the model was refined in two ways. The first was a structural change from a hexagon arrangement to superimposed triangles. This was introduced to illustrate complex and interleaved working practices, and to clarify groupings and interactions between all six variables. The second alteration included for the first time channels of information exchange (work-flows and communication). The amended model is shown Figure 6.19.

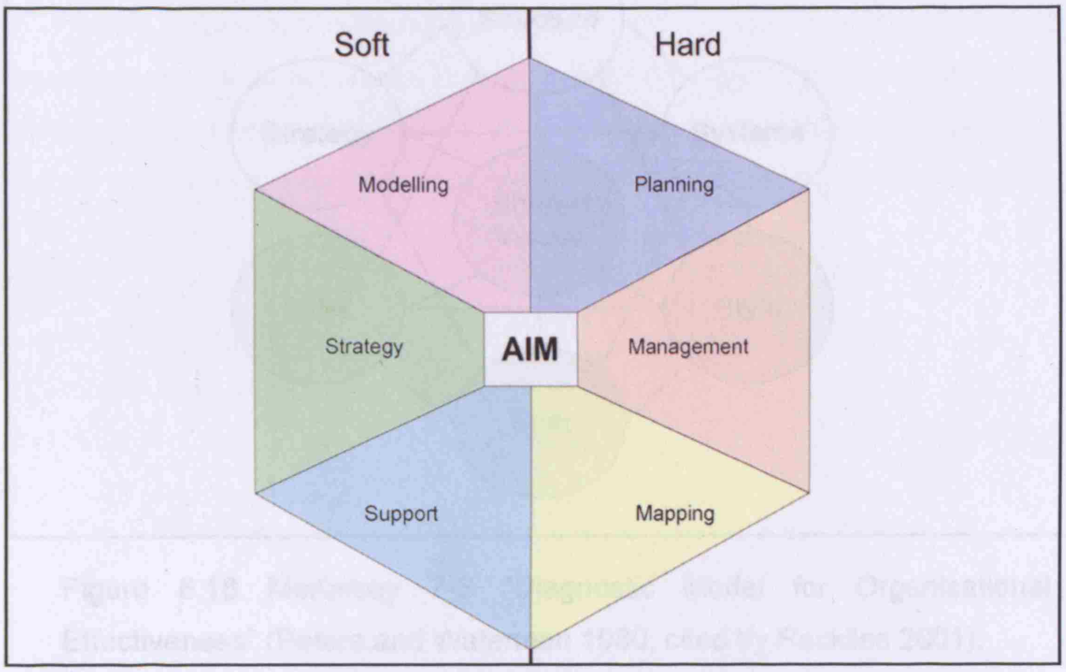

Figure 6.17 General model of value defined using the forestry sector, with two sub-disciplines added as a result of humanitarian aid consultation. This is an interim development, which cannot represent the working linkages or information exchange between themes of activity. The final model includes changes to address such considerations.

The revised structure is derived from the McKinsey 7-S model (Figure 6.18, Peters and Waterman 1980, cited by Recklies 2001), which advocates management of all seven business elements. The McKinsey principal is that organisation is not the result of structure. Management which focuses only on 'hard' components (illustrated Figure 6.18 and 6.19 by light shading) is unlikely to succeed. More intangible and 'soft' elements must also be included in decision-making for sustainable success. Recklies (2001) states that "the soft factors can make or break a successful change process, since new structures and strategies are difficult to build upon inappropriate cultures and values". Soft factors are resistant to enforced change, and rely on commitment and stakeholder "buy-in".

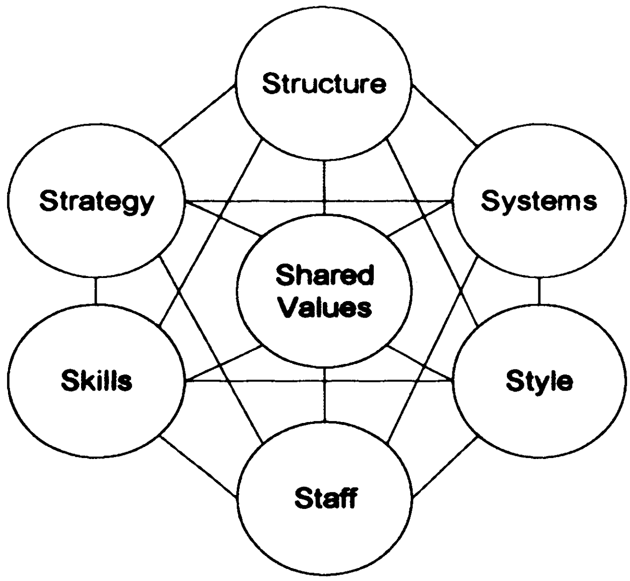

Figure 6.18 McKinsey 7-S "Diagnostic Model for Organisational Effectiveness" (Peters and Waterman 1980, cited by Recklies 2001).

The new structure, shown Figure 6.19 groups variables and facilitates discussion of their general inter-relationships. Two groups of three variables were chosen in a new structure comprising two overlapping triangles. Shading and layer differentiate the triangles, which are discrete but which share the same spatial domain. Although one floats above the other, they are of equal importance. The triangles broadly represent 'hard' and 'soft' approaches.

In order to reach a defensible and complete assessment, a detailed study of available and pre-existing data sources is required, to be distributed among working groups. It is vital that any comparison of data sources is consistent and accessible to all participants. All parameters should be fully specified and directly comparable, to support the assessment process[2].

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[2] Groups are advised to present budgets for data costs, but to avoid rejecting options on financial grounds. Cost burdens can commonly be shared between departments as part of a 'single expense, many uses' model.

The potential contribution of Earth Observation to each area of activity is evaluated separately, using interactive problem-solution analysis as introduced in section 5.7.1. Such evaluations can be concurrent and distributed throughout companies and organisations, although the format of reporting and feedback should be consistent. Splitting assessment into small areas of expertise limits the scope of discussions to create more focused and expert user-groups. Assessment-groups work independently at this stage.

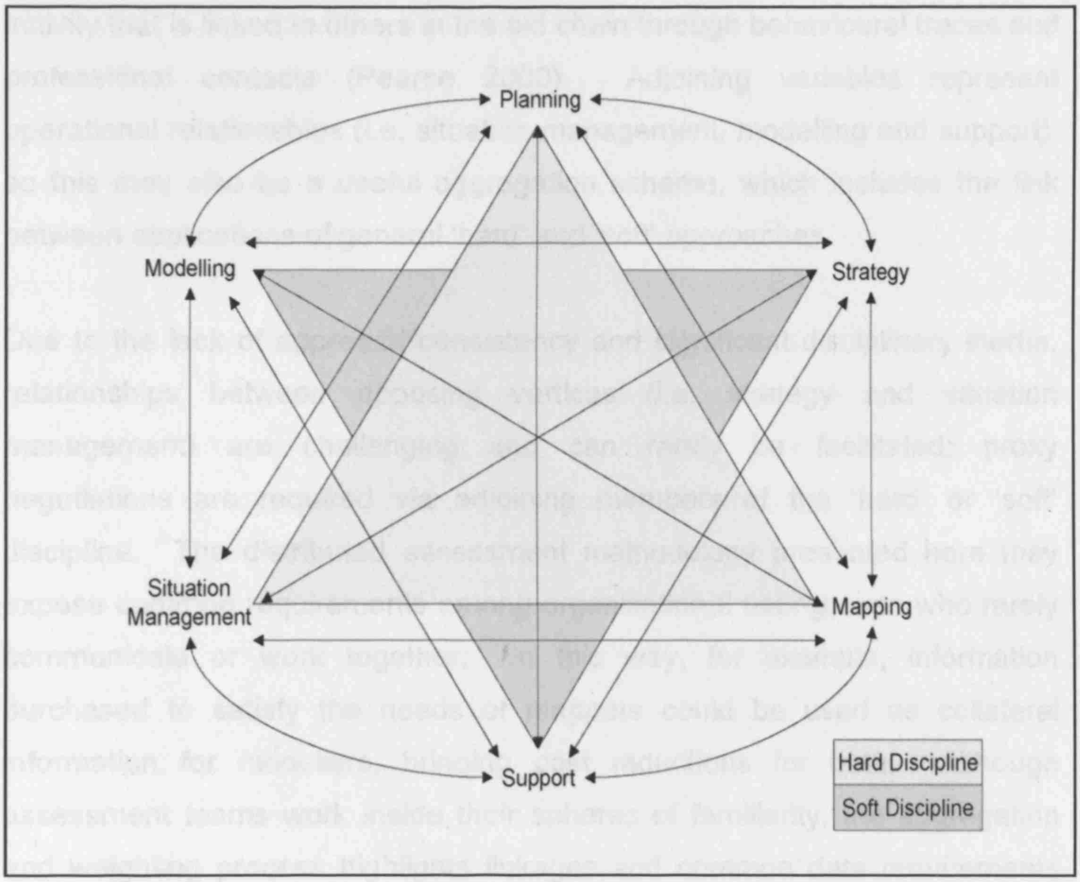

Figure 6.19 Revised general model of value, reflecting the broader pattern of activities found within the humanitarian aid sector. Model structure

The next phase in the value-assessment process aggregates results from expert user-groups. The level of aggregation is situation-dependent. For example, in a humanitarian context it may be most useful for an NGO to consider value-chains for one intervention (country X), for a single type of action (flood response), or for a time period (the first month). Just as foresters distributed value-definition questions to specialists and managers, aid workers can collate results from activities in different arenas. Further to this, more complex relationships between working disciplines have been established and made explicit in the model. For example, variables can be related by co-residence on the same triangle, indicating a general consistency of approach (i.e. planning, mapping and situation management). Each of the six triangle vertices represents a behavioural 'node'; a sphere of activity that is linked to others in the aid chain through behavioural traces and professional contacts (Pearce 2000). Adjoining variables represent operational relationships (i.e. situation management, modelling and support), so this may also be a useful aggregation scheme, which includes the link between applications of general 'hard' and 'soft' approaches.

Due to the lack of approach consistency and significant disciplinary inertia, relationships between opposing vertices (i.e. strategy and situation management) are challenging and can rarely be facilitated; proxy negotiations are required via adjoining members of the 'hard' or 'soft' discipline. The distributed assessment methodology presented here may expose common requirements among organisational user-groups who rarely communicate or work together. In this way, for example, information purchased to satisfy the needs of mappers could be used as collateral information for modellers, bringing cost reductions for both. Although assessment teams work inside their spheres of familiarity, the aggregation and weighting process highlights linkages and common data requirements normally obscured by institutional procedure or lack of communication.

In section 5.7.1, it was suggested that data purchasing and exploitation requirements could be weighted in order to allocate priority or urgency to user-groups. Just as with forestry, humanitarian organisations can choose from a large number of scoring schemes to order activities. Applications for Earth Observation data could be weighted by personnel-hours saved (or indeed fuel savings), by budget allocation, or by overall effect on humanitarian capacity. If required a more strategic level of aggregation can also be performed, to evaluate the most profitable spending areas in terms of increasing capacity and capability, and making efficiency savings. This would provide an agency-level insight into the net effect of Earth Observation adoption in a variety of areas. Comparisons could build on scenarios of no change, some adoption, and maximised Earth Observation usage (incorporating cost of uptake, replacement cost and opportunity cost in a non-technical way). Such cost-benefit models would allow reconciliation of new sources of information with organisational aims and objectives, while incorporating significant non-market elements of value through qualitative, aggregated expert analysis.

The revised value model provides a useful scheme for assessing the utility of Earth Observation data for the operational requirements of Forestry and Humanitarian Aid. The general model is recommended for other sectors, such as environmental monitoring, treaty compliance and legal enforcement, meteorology, oceanography and natural resource monitoring. Chapter 7 reviews the success, relevance and applicability of this approach, with reference to research questions, wider applications and legislation.

Chapter 7 DISCUSSION AND CONCLUSIONS

7.1. Introduction

The introduction to this thesis identifies shortcomings in methods used to attribute economic and social value to Earth Observation data. These approaches suggest that value can be captured in two ways; by observing market prices of data and by estimating social (non-market) contributions brought about through the scientific use of data. Neither approach is satisfactory because Earth Observation contributes to effectiveness in several ways within a diverse range of activities including scientific, legal, environmental, security and economic sectors.

A complete and applicable measure of total Earth Observation value enables greater understanding of complex, variable and non-market consumption patterns. Modelling consumer demand serves two purposes. Firstly, a complete value-capture methodology permits fair competition with more commercial alternatives in markets. Secondly, repeatable assessments of value allow informed management in the absence of traditional market forces. In real terms, these two benefits permit more defensible advocation of Earth Observation spending and policy weighting. In areas where important value-chains reside outside markets, or when markets for competing approaches (such as aerial photography or field survey) have matured, it is crucial to accurately and completely characterise previously 'missing markets' of Earth Observation data, in order to capture inherited value, non-market positive externalities and variable value-types. The obvious return on investment accessible through more conveniently assessed approaches has all too often led to their acceptance at the expense of Earth Observation, which has been undervalued and overlooked.

7.2. Conclusions

7.2.1. Publicness of Earth Observation

Detailed public / private goods analysis has been applied to Earth Observation for the first time, revealing complex and variable value-types across a range of data sets and exploitation arenas. The conclusions of this assessment suggest that urgent and widespread changes to Earth Observation data policy are required. It is proposed that the management scheme for data should be aligned with its embedded value characteristics, not superimposed by financial, political or organisational policy drivers, as is current practice.

This research indicates that the value-landscape of Earth Observation is complex and very variable; consequently, different types of Goods are optimally managed in very different ways. Flexible and adaptable data policies are required to reflect the unique value-characteristics of Earth Observation information products. Innovative excludability solutions such as encryption, pay-per-view and subscriber "multicasts" can assist effective management and dissemination of digital Earth Observation data; this avenue has not been adequately explored, but may hold special significance in the light of new legislation such as GMES and GEOSS, which will greatly increase the integration of Earth Observation data sets with governance (PWC 2006, Lautenbacher 2006).

Case studies of very different user-groups have assessed degrees of understanding and reliance on Earth Observation, and explored the uncaptured (inherited) value originating from these uses. The results have been used to assemble a conceptual model of value which aims to reveal the total 'true' value of Earth Observation data within an application by providing a decision support system (Figure 6.19, with implementation guide Section 5.7.1 and Appendix 3). Concepts of complex valuation and the Public-Private Good status of Earth Observation data sets were defined. The existence of hybrid and temporally-variable value-types has not yet been explicitly acknowledged within the Earth Observation community.

7.2.2. **Forestry and Earth Observation**

Following an examination of value and policy, the forestry sector provides an example of a commercial activity with emerging non-market elements which are linked to changing relationships between individuals and forest environments. As an environmentally significant land cover, forests are the subject of rapidly changing legislation which is likely to demand more detailed landscape information over the next decade. Traditionally costly intensive management regimes will be applied to spatially extensive areas which may have little economic potential.

Changing requirements bring operational and budgetary challenges, and some characteristics of Earth Observation recommend its use for management and monitoring. Foresters reveal defensive attitudes to Earth Observation which can be traced back to 'overselling' of disappointing capabilities in the past. Despite ongoing academic interest, the operational forestry market has not been developed by Earth Observation value-adding companies, and foresters are largely unaware of what data is available, where to find it, and what the real capabilities are. Some progress has been made working with Scandinavian nations, but satellite Earth Observation is not an operational approach in the UK. Absence of standardised information products and confusing costs (a by-product of inconsistent and sometimes inappropriate Earth Observation data policies) add to institutional inertia and structural limitations within UK public-sector forestry; together these issues have severely inhibited adoption of Earth Observation.

Informed by ineffectively managed components of value and parameterised using forester's comments, a new conceptual toolkit was developed to assist non-technical forestry professionals in accurately evaluating the in-sector value of Earth Observation data. The model, which is discussed in more detail in Section 5.7 and 7.3.3, functions as a structured decision support system to account for multi-use data and allow evaluation of weighted replacement costs and opportunity costs. This approach enables consideration of non-market elements of value within a simple framework, which can be easily implemented by regional and specialist forest managers.

7.2.3. Humanitarian Aid and Earth Observation

The humanitarian aid sector was used as a second case study, to explore non-market applications of Earth Observation data, and to test and refine the value-model. In contrast to the forestry sector, humanitarian aid activities lack commercial potential and reside almost entirely in the non-market sector as Merit and Public Goods. This has led to very limited market development activity, but it has not prevented aid agencies from using Earth Observation.

For some humanitarian interventions, timely and appropriate satellite-derived information has no substitute. Humanitarian users of Earth Observation data were most likely to be from governments and the UN. Interviewees suggested that Earth Observation functions as an enabling technology in humanitarian activities, bestowing capabilities on agencies that they did not previously have. Despite this positive impression, some operational shortcomings were identified; 85 per cent of respondents noted that the time-lag involved in data acquisition is unacceptable, and almost all respondents agreed that it was desirable to collect a catalogue of pre-event data for vulnerable areas.

In addition to industry-specific outcomes, aid workers supported the conclusions of the forestry community. For example, both user-groups agree that site visits remain essential even if well-developed Earth Observation solutions are available. Both case studies also suggest that some of the most important benefits of the use of satellite images reside outside markets; improved decision-making, more effective and efficient deployment of staff and more sharply focused management and mitigation activities. Non-market elements of Earth Observation data value have in the past been poorly characterised due to simplistic valuation schemes, which has led to a perception of poor sectoral performance (discussed in Section 3.2.2), and insufficient consideration of Earth Observation approaches in policy decisions. Comments and experiences of aid professional contributed to the refinement of the previously developed model of value, to include more variables and a more incisive structure.

7.2.4. **Cross-Cutting Conclusions**

Earth Observation marketing and data policy is incompletely developed, leading to confusion and unease among forestry and humanitarian aid user-groups (Millard et al. 1998, Rosenholm and Harris 2002). Engaging with current Earth Observation policy is difficult for users and stakeholders because approaches are fragmented and inconsistent (Ito 2005), relating only indirectly to controlled data.

Requests from the legal sector to simplify Earth Observation policy and provide usage guidelines apply equally to forestry, humanitarian aid and many other Earth Observation markets. Standardised, approved and validated processing strategies, with rigorous audit trails, are required to preserve the probity of digital data. Expert testimony and explanation reassures users and customers of the rigour and applicability of digital evidence, and a greater connection with the technical and scientific community helps to bridge the 'knowledge gap' between suppliers and consumers of data (Ainsworth et al. 2001). If the data management requirements of the legal sector were met, other Earth Observation user-groups would benefit. Humanitarian aid workers would have access to more streamlined processing and a reduced administrative overhead, addressing a stated need (Bjorgo 2006), and forestry workers would see cost effective and rigorously validated approaches that could be integrated with legislation, as is the case with the Finnish multi-source forest inventory product (Tomppo 2006, Section 5.3.5).

Adoption of consistent and well-developed processing workflows in Earth Observation may allow more accurate assessment of the costs associated with remote sensing solutions in areas where cutting-edge processing is not required. A menu of simple products may be a suitable solution for business areas where non-market Public Good values are less significant, allowing rapid comparisons of approaches. In these circumstances, the simplicity of this approach offsets its primary shortfall; there is no assessment of externalities and non-market outcomes. The exclusion of non-market effects leads to "asymmetrical" value-capture and 'missing' markets, which commonly precede undervaluation and mismanagement (Nordhaus and Kokkelenberg 1999). Simplistic valuation schemes which neglect complex value-types suppress the influence of human welfare considerations by excluding non-market components of value. Increasingly, examination of previously "missing markets" is a requirement for monitoring sustainability, assessing the impact of environmental goods and services and international treaty compliance (de Groot et al. 2002).

Themes of transparency, intelligence, diplomacy and compliance emerged during this research. The military origin and public sector dominance of spaceborne remote sensing has been discussed, and Earth Observation has been compared to more numerous (and more completely legislated) digital data-gathering devices such as forensic photography, speed cameras and CCTV. Although Earth Observation is covert, data remains admissible and measures can be taken to preserve the evidential integrity of digital sources. In this context, the advantageous qualities of spaceborne remote sensing have been recognised; broad spatial coverage combined with fine resolution, permissive sensing supported in law, and increasingly timely digital data. Earth Observation has been employed by governments, NGOs and business entities to characterise activities that were not otherwise accessible due to conflict, political constraints or natural hazard events. The outcomes of these interventions are broad-ranging, from agricultural subsidy monitoring and UN humanitarian interventions to public dossiers on weapons of mass destruction and improved business intelligence.

An analysis of Public / Private Goods and Earth Observation reveals that value-properties of Earth Observation data have been incompletely considered in policy development, leading to inflexible and general data policies that deter potential users, limit exploitation opportunities and inhibit uptake. Policy problems are exacerbated by a knowledge gap which exists between suppliers and users of data, explored using detailed case studies.

From the user side, both studies reveal workers who are under pressure to satisfy demanding information requirements. All participants were influenced to some degree by human prejudice and experience. Historical overselling of Earth Observation capabilities leads to suspicion among some users; others react defensively to new approaches, fearing that Earth Observation is a technology-based replacement for human expertise - without realising that it is a complementary, augmenting approach which may assist them in working more efficiently and effectively.

An unresponsive and remote supplier community bound by inflexible policy is not welcoming for users with incomplete, obsolete or specialised knowledge, so they are unlikely to seek guidance. The 'map' of data publicness provided by this research (Figure 4.3) indicates that data sources are variable in their value-characteristics; it seems that the requirements of the user community are just as varied, and that significant progress is required in policy development and outreach.

Institutional inertia has also been identified in both user-groups as a significant uptake inhibitor. In operational forestry and humanitarian work, changes in protocol are considered carefully; overheads for training and new equipment are difficult to justify, and 'teething troubles' which reduce productivity are unacceptable. Running new and old methods in parallel is a costly luxury, so the least risky policy to ensure deliverable results is to change nothing and sacrifice small steps in capability.

Limited outreach from data providers has led to user frustrations about data availability, cost, timeliness, coverage, processing, interoperability, quality and licencing. In some cases, providers have been able to address potential users through collaborative academic work, and successful market penetration has been the result of publicity and distribution by programmes such as UN Respond and MapAction. In most cases, publicly-funded sensors are distributed to a small scientific and government community, so there is no perceived requirement for additional awareness. In others, commercial providers inevitably focus customer development activities in areas where return-on-investment is greatest.

A brief examination of model applicability in a variety of application environments tests interdisciplinary performance. This new model of value consistently captures components of value which have in the past been incompletely or poorly represented. Non-market benefit streams in the form of socio-cultural impacts, strategic decision-making and information-collection have been increasingly recognised as key outputs of Earth Observation activities in Europe through GMES and globally through the Global Earth Observation System of Systems (GEOSS). GEOSS provides a suitable evaluative environment in nine thematic areas, shown on Table 7.1.

Applied to areas of special societal benefit defined by GEOSS, the decision support system recommended here performs well and remains relevant and applicable. The six sub-disciplines used to populate the model remain applicable across contexts, reinforcing its interdisciplinary potential. This new approach to Earth Observation value effectively addresses concerns raised in the introductory chapter, and provides responses to research questions which are revisited in this concluding chapter. Contributions to understanding have been made at the level of chapter conclusions (which concern innovative valuation approaches and new interactions with foresters and humanitarian aid workers), and through the development, refinement and brief validation of a new conceptual model of value.

Table 7.1 Societal benefit areas identified by the Global Earth Observation System of Systems (GEOSS, Christian 2005, Lautenbacher 2006), and the applicability of the new model of value proposed in this research. Key: (x) high model utility, (o) intermediate model utility, (-) reduced model utility.

Societal Benefit Area	Planning	Mapping	Management	Modelling	Strategy	Support	Conclusions
Reducing loss of life and property from natural and human-induced disasters	x	x	x	x	x	x	Humanitarian Aid was examined in depth in Chapter 6
Understanding environmental factors influencing human health and wellbeing	x	x	x	x	x	-	Identification tracking and prediction of malarial zones could target resources
Improving management of energy resources	x	x	-	x	x	o	Satellite-based identification of valuable resources, such as water and oil
Understanding, predicting and mitigating climate variability and change	o	x	x	x	x	x	Improved focus of mitigation activities, modelling Carbon balance and climate
Improving water resource management by better understanding the water cycle	x	x	o	x	x	x	Earth Observation data supports watershed and global climate modelling
Improving weather information, forecasting and warning	-	x	x	x	-	x	Improved utility company energy usage forecasting could save US $1 billion / yr
Improving the management and protection of ecosystems	x	x	x	-	x	x	Management of spatially extensive and remote areas supported by EO data
Supporting sustainable agriculture and forestry, combating desertification	x	x	x	x	o	o	Forest management and monitoring is examined in depth in Chapter 5
Understanding, monitoring and conserving biodiversity	x	x	x	-	x	-	Earth Observation provides key data for monitoring deforestation and rangeland

7.3. Research Questions

It is useful to briefly revisit the research questions posed in Section 2.3. The questions provide a framework for assessing the contribution to knowledge offered by this thesis, and provide a summary of overall conclusions.

7.3.1. How is it possible to accurately capture and present the social and economic value of Earth Observation data?

New and innovative approaches are required to capture value in Earth Observation, because existing strategies incompletely represent complex value types, which can lead to sector undervaluation. Strategies from other disciplines provide guidance. Frameworks for approaching value, developed in the fields of law and environmental economics, can be adapted and applied to Earth Observation. Few other goods or services possess value-characteristics as variable as those found in Earth Observation. In this thesis, variability of value characteristics between sensors, agencies and product types was discovered and mapped in an innovative Public / Private Good feature space. Alongside newly-identified temporal variability, these issues pose significant management and policy challenges, and may explain problems that have arisen in the past.

A paradigm shift is required within Earth Observation to reflect insights which suggest that value is composed of distinct ingredients in variable proportions. Effective and sustainable provision of Goods therefore requires a complete evaluation of their value characteristics. This approach is novel in the field of Earth Observation. It is a logical and defensible basis for new data policy. Quantification of non-market value-types is extremely challenging and no single valuation approach adequately represents Earth Observation characteristics. At policy-level, more explicit acceptance of the non-market influence of Earth Observation is required. It has been noted that, in some circumstances, implicit acknowledgement of Public Good and Merit Good value has already occurred. New initiatives such as GMES and GEOSS aim to address this issue by referring to "societal benefits" as important areas of

Earth Observation influence and development (Christian 2005). For users of Earth Observation, quantification of social value is an unrealistic objective; estimation procedures are complex and require data that is not easily accessible. In addition, no single methodology for capturing passive use values can be recommended for Earth Observation. In response to these problems, a non-technical conceptual decision-support approach is proposed, that enables repeatable estimates of Earth Observation value to be made. The model uses an aggregated problem-solution approach based on six generalised sub-disciplines

7.3.2. To what degree is Earth Observation socially profitable, are 'missing markets' important and how can they be incorporated into valuation approaches?

Public Good and Merit Good activities typically contribute to human welfare without passing through markets. They often generate benefit streams that are social in nature, which can be labelled 'social profits'. Although Earth Observation activities have in the past been implicitly identified as 'a good thing', it is important to accurately and formally classify data sources. This thesis classifies nine Earth Observation sensors according to their Public Good status. In general terms, and more specifically in Forestry and Humanitarian Aid, Earth Observation data sources have been shown to make significant non-market contributions through a wide variety of mechanisms, discussed throughout this thesis. These contributions are omitted from most accounting practices; positive influences that are attributable to the use of Earth Observation are 'missing' from reporting. In this way missing markets cannot contribute to the reported development of the Earth Observation marketplace, which is commonly compared to more commercial activities. Despite demonstrably augmenting capacity or capability in many activities (such as forestry or humanitarian aid), financial reporting does not reflect true performance.

A key component of 'missing markets' is the concept of value-inheritance, introduced in Sections 5.3.5 and 6.4.2.2. Availability of improved information for decision-making may be directly attributable to Earth Observation, but the financial effects of the (improved) decisions are disconnected. The positive influence of Earth Observation is masked by traditional reporting conventions. To extend this concept, decision-making activities with greater significance impart greater value to data. For humanitarian aid and disaster response, it is easy to see that data used to save large numbers of lives accumulates very large 'inherited' value. This societal value is not traceable through markets, and remains invisible. Incorporating social elements into data valuation requires a shift in policy emphasis, which may already be underway; consideration of "societal benefits" and contributions to the "socio-economy" are incorporated in new programme objectives in Europe and the US (GMES and GEOSS, Christian 2005, Werle 2005).

7.3.3. Can a simple approach provide a logical, robust, consistent and interdisciplinary measure of total Earth Observation value?

A new general model for assessing value has been developed in the course of this research. It was parameterised using input from the forestry community and refined using input from humanitarian aid professionals. Using six common activities, the model provides a non-technical approach for estimating in a robust and repeatable way the total value of Earth Observation. Design and deployment of the model is discussed in Sections 5.7 and 6.5.

Figure 7.1 illustrates the strategic position of the model in the decision-making process. As part of a feedback loop, this model of value informs better choice and evaluation of strategic options for managers; in this way the model does not necessarily advocate Earth Observation, but provides greater scope for its application by circumventing traditional approaches which do not accurately and completely represent value. It is of economic and socio-cultural benefit for individuals, agencies and governments to use appropriate data sources; if previously uncaptured benefits of Earth Observation (in spheres of economic, social and non-market influence) are more completely considered alongside other approaches, the effects of some inhibitors to the evaluation and adoption of Earth Observation may become less significant.

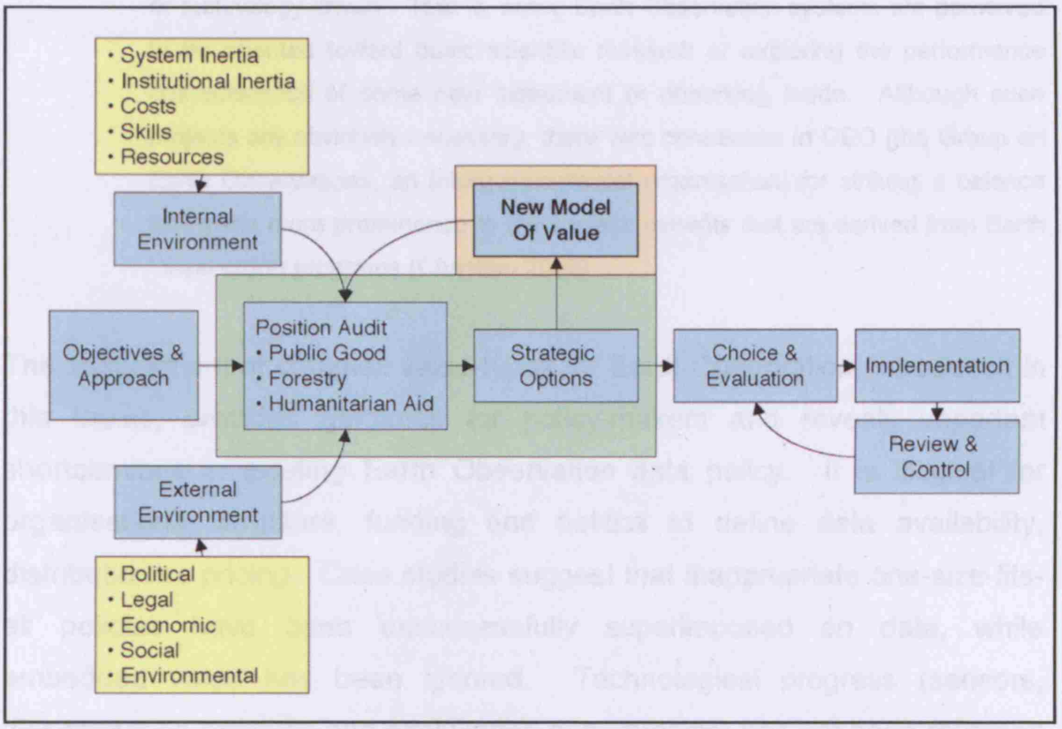

Figure 7.1 Strategic map of thesis objectives, showing the position and function of the general model as a tool for capturing and evaluating complex value. Reprinted from Figure 2.3. The model enables non-technical Earth Observation users to qualitatively assess the replacement value and opportunity cost of data in applications where benefits reside outside markets and where outcomes can be considered Public or Hybrid Goods. A diagrammatic implementation guide is included in Appendix 3.

7.4. Concluding Remarks

> Earth Observation programs are sometimes seen as primarily curiosity-driven or technology-driven. That is, some Earth Observation systems are perceived to be oriented toward basic scientific research or exploring the performance characteristics of some new instrument or observing mode. Although such projects are obviously necessary, there was consensus in GEO [the Group on Earth Observations, an intergovernmental organisation] for striking a balance that gives more prominence to the societal benefits that are derived from Earth Observation programs (Christian 2005)

The assessment of complex value-types for Earth Observation, introduced in this thesis, provides guidance for policy-makers and reveals important shortcomings in existing Earth Observation data policy. It is illogical for organisational structure, funding and politics to define data availability, distribution or pricing. Case studies suggest that inappropriate one-size-fits-all policies have been unsuccessfully superimposed on data, while embedded value has been ignored. Technological progress (sensors, dissemination conduits and exploitation opportunities) has not been reflected in policy change. As a result, management schemes in Earth Observation are simplistic and inflexible. Accurate classification of embedded value-types leads to defensible recommendations for optimal management. This is an avenue for further research that should be explored in depth and with urgency.

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APPENDIX 1 FORESTRY QUESTIONNAIRE

Dear Sir or Madam,

I am currently engaged in PhD research funded by the ESRC, BNSC and University College London, which involves working to accurately capture the social and economic value of Earth observation data. This work will provide a framework to assist in policy-making and compliance with national and European legislation.

My current area of research focuses on the forestry and forest product sector, where initial results suggest that Earth observation data can successfully support existing operational management strategies. I would very much appreciate it if you could spare a moment to fill in the attached questionnaire, which will form a key part of the doctoral study due for publication in September 2005. If this is not convenient, alternative arrangements can be made by contacting me on +44 (0)20 7679 4287 or via e-mail. Telephone interviews should take around 5 minutes, and can be arranged at your convenience.

The response from this consultation will play a key role in guiding the research over the next 3-4 months, during which time I will work within the forestry sector. The primary experimental outcome will be user-friendly biophysical and spatial information sources for use by managers and field staff. Through this consultancy exercise, I aim to establish an ongoing dialogue with potential end-users of new data products. Further details of the project roadmap can be provided upon request. A central aim of the research is to assess independently the contribution to forestry that can be made by new technologies such as aerial photography and satellite remote sensing. You have been selected as a recipient based upon your professional experience or current position, and so your input at this critical point in the research would be greatly appreciated.

Thank you once again for your time and expertise,

Lewis Miller

What is your role in your organisation? What responsibilities do you have?
What strategies for forest management does your organisation currently employ?
What limitations and problems have you encountered with data collection and management?
Have satisfactory solutions been found?
What could be done to improve the accuracy, efficiency and simplicity of forest management?
What forestry variables would you ideally like to work with?
How often should the data on these variables be updated? In order to work effectively, what do you really need to know?
What sources of data does your organisation currently use? Ground Survey ☐ Ground Survey using: PDA ☐ / GPS ☐ / DGPS ☐ / Other (specify below) ☐ Aerial Photography ☐ (visible ☐ / infra-red ☐ / multispectral ☐) Map Interpretation ☐ Satellite Imagery (please specify below) ☐ Comments:

Thank you very much for your help. Please supply the names of colleagues who might be able to help in this research:	
Name:	
Email Address:	
Organisation:	
Name:	
Email Address:	
Organisation:	
And finally – are there any issues you feel have not been raised by these questions, that you would like to see addressed?	
Would you be willing to be contacted again? Yes ☐ / No ☐	

Thank you very much for your time. If you have any questions or comments, please feel free to contact me. If you have any questions or further contributions, a space is provided below.

<u>You should submit your response by email, if possible.</u>

Lewis Miller

The Social and Economic Value of Earth Observation Data

APPENDIX 2 HUMANITARIAN AID QUESTIONNAIRE

Dear Sir or Madam,

I am currently engaged in PhD research funded by the ESRC, BNSC and University College London, which involves working to accurately capture the social and economic value of Earth observation data, to provide a framework to assist in policy-making and compliance with national and European legislation.

My current area of research focuses on the humanitarian aid sector, where initial results suggest that Earth observation data can successfully support existing operational management strategies. I would very much appreciate it if you could spare a moment to fill in the attached questionnaire, which will form a key part of the doctoral study due for publication in September 2005. If this is not convenient, alternative arrangements can be made by contacting via e-mail. Telephone interviews should take around 5 minutes, and can be arranged at your convenience. The response from this consultation will play a key role in guiding the research over the next 3-4 months, during which time I will work within the aid and disaster response sector. I aim to establish an ongoing dialogue with potential end-users of new data products to assess **independently** the contribution to aid response that can be made by new technologies (such as aerial photography and satellite remote sensing). Your input at this critical point in the research would be greatly appreciated.

If possible, please forward this message to colleagues or associates who may be able to contribute. For your convenience, an online version of this questionnaire can be found at: www.pm-04.com/survey.html

It would be most helpful to my research if you could respond by 31 January 2005. Thank you once again for your time and expertise,

Yours sincerely

Lewis Miller

What kind of organisation do you work for?

☐ - National Government

☐ - Local Government

☐ - UN

☐ - Donor Organisation (type:)

☐ - Non-Governmental Organisation (☐ Local / ☐ National / ☐ International)

☐ - Commercial

☐ - Other (please specify:)

What is your role in your organisation? What responsibilities do you have?

Does your organisation regularly use geospatial information (maps, satellite images, aerial photography, charts and diagrams)?

☐ - Yes

☐ - No

What sources of information does your organisation currently use?

Ground Surveying ☐

Mapping ☐

Field Devices: PDA ☐ / GPS ☐ / DGPS ☐ / Other (specify below) ☐

Aerial Photography ☐ (visible ☐ / infra-red ☐ / multispectral ☐)

Satellite Imagery (please specify type below) ☐

Map Interpretation / redrawing ☐

Comments:

Which of the sources you have identified are vital to your work?

What limitations and problems have you encountered with data collection and management?
What solutions have been developed to work around these problems?
What measures could be taken to improve the access, efficiency and simplicity of data supply to the aid and disaster response community?
What key information do you most commonly need for response, preparedness and monitoring activities?
What time-lag is associated with the acquisition of geospatial information? What is the most rapidly available data format?
Would more rapid access to data improved response effectiveness?
How often should the data be updated?
Is it beneficial to have pre-event sources of spatial information?
Please check the box if you have heard of, or used, the following data: UN Respond - Unfamiliar ☐ / Familiar ☐ / Have Used ☐ / Would Consider ☐ AlertNET - Unfamiliar ☐ / Familiar ☐ / Have Used ☐ / Would Consider ☐ UNOSAT - Unfamiliar ☐ / Familiar ☐ / Have Used ☐ / Would Consider ☐

Thank you very much for your help. If you know of a colleague who might be able to help in this research, please add contact details here:

Name:	
Email Address:	
Organisation:	

And finally – are there any issues you feel have not been raised by these questions, that you would like to see addressed?
Would you be willing to be contacted again? **Yes ☐ / No ☐**

Thank you very much for your time.

If possible, please email your response by clicking here .

Lewis Miller

The Social and Economic Value of Earth Observation Data

APPENDIX 3 VALUE MODEL IMPLEMENTATION GUIDE

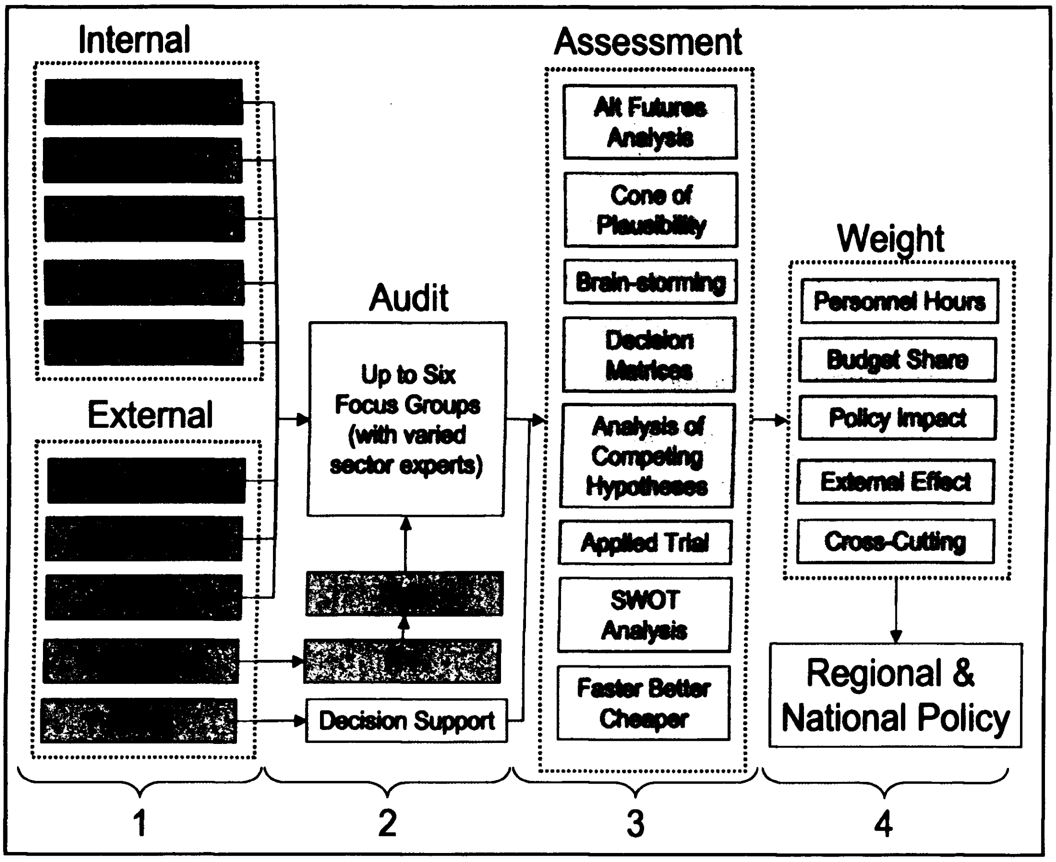

Figure 8.1 Implementation guide for value-appraisal decision support system (the General Model of Value discussed in sections 5.7.1 and 6.5). The approach provides a non-technical means of benefit-cost assessment incorporating non-market values and multi-use data. During the first phase of implementation within an organisation, internal and external factors affecting the value of new data are collated. Internal factors include current best-practice operating costs and business processes, data policies and the make-up of existing user-groups. External factors include potential sources of data, the attributes of available data, and the maturity of data understanding, sampled through peer-reviewed literature. For an assessment of costs to be up to date and applicable, an Invitation to Tender (ITT) process is recommended. Finally an assessment of data value is required, taking non-market factors into consideration. A detailed explanation of value-types and characteristics is found in section 4.2.7.

The second phase of assessment includes an independent audit of each key activity (identified for forestry on Figure 5.15 and for humanitarian aid on Figure 6.19). Expert focus groups review and collate findings of the first phase, before applying recognised analytical techniques during phase three. It is crucial at this stage that the reporting framework used by focus groups is consistent, and applicable to all analytical approaches. The final phase of the decision support system involves weighting the recommendations of audit boards from different business units or areas of expertise. Several weighting schemes are suggested in this Figure and in section 5.7.1. The existence of cross-cutting benefits (where acquisitions for one high-priority purpose are useful for another lower priority area) can be identified here. The final phase also links model outputs with policy drivers and external influences, to evaluate the contribution that new data can make to the fulfilment of regional, national or international objectives.